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Assessing the Anaerobic Characteristics of Children

A Doctoral Thesis

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DEDICATION

This thesis is dedicated to a very supportive and caring family. Specifically I dedicate it as a symbol of thanks to my mother and father for the love, devotion, and respect that they have given to me. I extend my gratitude to my sisters and their beautiful families for providing much encouragement and enjoyment in my life. I also dedicate this thesis to the memory of a grandfather whose sense of family love, justice and commitment remain a most powerful inspiration in my life.

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Abstract

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Chapter One

Introduction

Chapter One

Introduction

Within society, there is a greater emphasis than ever before on younger children pursuing sporting activities. Commensurate with this is a growing demand for governmental and independent institutions to provide policies on child participation in physical activity (A.A.P., 1988; A.S.M.F., 1989; Corbin and Pangrazi, 1992; F.I.M.S., 1991; N.H.M.R.C. 1989, Siegel, 1989; Simons-Morton et al., 1988; Susman et al., 1992; Young, 1988). Although the statements are often strongly opinionated, they often appear to lack a sound physiological foundation. A wealth of publications is available on the exercise and training responses of adults. Yet there are comparatively fewer publications on the exercise and training responses of healthy, child-based populations. The relative dearth of knowledge of pediatric exercise responses compared to adults, is partially due to moral and ethical concerns which restrict invasive and intrusive research (Bar-Or, 1983; Jonsen, 1978; Rowland, 1989). Existing guidelines recommend that research with children must have a valid purpose and must offer the children experiences which do not largely deviate from risks encountered in their everyday lives. Therefore, protocols must exclude traumatic, dangerous, and invasive techniques such as muscle biopsies, or low-protein diets (Rowland, 1989).

As well as ethical and moral issues, the dearth of research on children may also be partially attributed to research in pediatric exercise science being a relatively recent field of study. Earlier research tended to provide large anthropometric profiles of growth patterns in children (Parizkova, 1964; Tanner, 1962). However, it was the formation of the European Pediatric Exercise Science Group in 1968 which provided the catalyst to support and foster a new perspective on the exercise responses of children. A large proportion of these studies have involved aerobic responses of children. Not as much is known about the anaerobic characteristics of children (Bar-Or, 1983; Zwiren, 1989).

Anaerobic activities complement the short attention span and spontaneous, explosive nature of physical activity preferences in the child. Energy demands from anaerobic sources are also present in the majority of organised sporting activities chosen by children. Indeed, it is often the excellence in anaerobic-based activities which denotes outstanding performances in children. To date, much of the research on the anaerobic characteristics of children has centred on Oded Bar-Or and the Wingate Institute group of researchers. The Wingate Anaerobic Test (WAnT) requires short-term performances (e.g. 30 s) of all-out cycling or arm cranking against a fixed braking force. Yet in reviewing the WAnT, Bar-Or (1987) and Vandewalle et al. (1987) both believed several issues remained unresolved in the pursuit of optimal testing conditions for children. Saltin (1990) challenged whether the recommended 30 s for the Wingate anaerobic test was an appropriate duration to exhaust the capacity of anaerobic energy supplies in the body.

Hermansen and Medbϕ (1984) and Medbϕ and various other co-workers (1988, 1987, 1989, 1990, 1991) are the principal researchers behind a recent protocol for determining the anaerobic capacity of subjects, known as the accumulated oxygen deficit method. In this method the power-O_2 relationship, obtained under steady state submaximal conditions, is used to predict the theoretical oxygen demand of supramaximal exercise. The difference between the predicted oxygen demand and the actual oxygen cost over the duration of the test to exhaustion is described as the accumulated oxygen deficit. Medbϕ et al. (1988) determined that anaerobic capacity was not reached until at least 2 minutes of running to exhaustion at supramaximal intensity. Other authors (Gastin, 1992; Withers et al., 1991) have reported maximal anaerobic capacity values within 1 minute of cycling under supramaximal conditions. To date, all of the anaerobic capacity data from the use of the accumulated oxygen deficit method have been reported in adult populations.

A number of related investigations were devised on the anaerobic characteristics of children as a consequence of evidence and postulations made within the previous literature (Bar-Or, 1983, 1987; Naughton, 1989; Saltin, 1990; Vandewalle et al., 1987; Zwiren, 1989) This research, involved a series of four investigations which have profiled anaerobic performances of children.

Purpose

The purpose of this research was to provide a better understanding of the assessment and cross-sectional development of the anaerobic characteristics of children aged 6-12 years. Specifically, a series of four related-studies were conducted. These studies had the following respective purposes:

(1) To examine the anaerobic performance responses of children (aged 6-12-years) to four different load applications for the WAnT.

(2) To identify the extent to which male children (aged 6-12-years) varied in several repeated performances of the WAnT over a period of four weeks. This series of tests also examined the effect of a computerized feedback game which was linked to the pedal frequency, on the variability of children's performances on the WAnT.

(3) To determine the maximal anaerobic capacity of 11-year-old males and females using the accumulated oxygen deficit method during supramaximal cycling exercise bouts against constant power resistances representing 110, 130, and 150 relative percent of peak oxygen uptake.

(4) To obtain maximal accumulated oxygen deficits in 11-year-old males and females from supramaximal cycling exercise utilizing isokinetic resistance to exhaustion.

The objective of the series of studies was to obtain a broader profile of the anaerobic responses of children. than had been previously available. It investigated several key issues within the anaerobic profile of children 6-12-years-of-age which will be useful in future testing, talent identification and/or the exercise prescription of children.

Rationale

The rationale behind this research argues the need for a greater understanding of the anaerobic nature of children. The aerobic responses of children to exercise under many different conditions have been well documented (Bar-Or, 1983, Rowland, 1990). Limited information is available on anaerobic responses of children to a variety of testing protocols. The inability to identify the direct causes of an attenuated anaerobic response of children to exercise when compared with adults warrants a greater body of information. The findings of the present research will meet contribute to a greater body of knowledge on child-based protocols for testing pediatric populations in laboratory situations.

Limitations

In conducting the study, the following limitations are recognised:

1. Within the framework of the study no attempt was made to alter the lifestyle of the children outside the laboratory situation. Thus the physical activity pattern, dietary choices, attitudes, emotional status, and social environment of the children were not investigated.

2. A further limitation of the investigations of the children in this research was the moral and ethical constraints imposed by the type of laboratory testing deemed appropriate for children under 12 years of age. Specifically, it was considered unethical and unnecessary to include invasive protocols such as muscle biopsies and blood collection.

Delimitations

1. Firstly, the research was delimited to samples of children from the same inner suburban primary school in Melbourne. Each of the studies were delimited to the population of volunteers, rather than randomly selected samples.

2. The other general delimitation was imposed by the nature and quantity of tests performed by the subjects. Tests were predominantly physiological in nature. Sociological and emotional factors were not assessed.

Definition of terms

The following definitions of terms were adopted for use during the study:

Anthropometric measures:

These terms refer to body size, composition, and structure measures:

Height (cm) -	The linear size measure of the body
Mass (kg) -	The total mass of a person
Body Surface Area (m^2) -	An index of the total surface area of the body (0.00718 x [Mass $(kg)^{.425}$] x [Ht $(cm)^{.725}$]) (DuBois and DuBois, 1916)
Skinfold measurements -	An indication of subcutaneous fat development at a specific site on the body.

Cardiorespiratory function measures

This term refers to the measures adopted to reflect cardiovascular and respiratory function of the children in the study.

Peak oxygen uptake - the peak rate of oxygen utilization of a child during an incremental cycling test to volitional exhaustion or the achievement of predetermined maximal criteria which have been observed previously (Zwiren, 1989). Peak oxygen uptake is expressed as absolute ($l \cdot min^{-1}$) or relative to the body mass ($ml \cdot kg^{-1} min^{-1}$).

Ventilatory threshold - the workload corresponding to a disproportional increase in the VE/VO_2 ratio without a concomitant increase in the VE/VCO_2 ratio during exercise with short, incremental rises in resistances (Reybrouck, 1989; Wasserman, 1984). It is also denoted by a deviation from the line of identity created when the VO_2 and VCO_2 responses are plotted against each other (Beaver et al., 1986). It is representative of respiratory responses to metabolic change at the cellular level.

RER - the respiratory exchange ratio is the ratio of the volume of expired carbon dioxide to the volume of expired oxygen (VCO_2/VO_2). As the amount of VCO_2 increases with effort, RER values in excess of 1.0 have been used an index of approaching peak maximal effort in pediatric populations (Zwiren, 1989).

Anaerobic function measures

This term refers to measures adopted to reflect work at high intensity over relatively short periods of time.

Peak power - the highest mechanical power output elicited at any one tenth of a second over the 30 s of all-out cycling on a modified bicycle ergometer. Results are expressed in watts (absolute terms) or watts per kilogram of body mass (relative terms).

Mean power - the averaged mechanical output sustained over the duration of the test and is expressed in absolute and relative terms (watts and watts per kilogram of body mass).

Fatigue index - the measure of the power decrement incurred during highly intense exercise as a result of fatigue and is calculated at the percentage difference between the peak and final power outputs.

Anaerobic capacity - the maximal amount of ATP calculated to be produced from anaerobic sources during supramaximal exercise to exhaustion. The anaerobic capacity is most frequently presented as the O_2 equivalent of this amount of ATP and is thus expressed in litres and, or $ml \cdot kg^{-1}$.

Maximal accumulated oxygen deficit - the difference between the predicted oxygen cost for supramaximal intensity exercise and the actual accumulated oxygen uptake achieved within the duration of the time to exhaustion.

Chapter Two

Review of Literature

Chapter Two

Review of Literature

This review of literature discusses anaerobic responses to high intensity exercise. It is divided into the following major sections; anaerobic metabolism in humans, specific anaerobic responses of children, and testing anaerobic characteristics.

1. Anaerobic metabolism in humans: an overview

Anaerobic energy sources are used when the demand for work is high, or intermittent. Anaerobic metabolism is also denoted by bursts of musculoskeletal strength and power. During predominantly anaerobic exercise, the rate of oxygen uptake or delivery is not sufficient to meet work demands. Energy sources at the onset of highly intense exercise are principally fuelled from anaerobic energy stores. These stores exist in the form of adenosine triphosphate (ATP), phosphocreatine (PCr) and glycogen. ATP is the primary energy source for muscular contraction; however, ATP stores in muscle are limited. There is approximately 5 mmol/kg wet wt muscle of stored ATP within the skeletal muscle, with a turnover rate close to 1 $mmol \cdot s^{-1} \cdot kg^{-1}$ (depending on the exercise intensity). Consequently, ATP requires constant resynthesising. Resynthesis of ATP can occur aerobically or anaerobically. Anaerobic resynthesis of ATP occurs via the breakdown of PCr and of glycogen to pyruvate and ultimately to lactate. Under heavy exercise demands, the sequence of predominant energy sources in anaerobic metabolism begins with the ATP stores within the muscle. As the immediately available stores of ATP deplete to a particular level, anaerobic energy is more prominently accessed from the breakdown of the high energy phosphates from PCr. Skeletal muscle contains three to four times more of PCr than its immediate stores of ATP. From the start of high intensity exercise to exhaustion, stores of muscle ATP and PCr can decrease by 20% and 80-90%, respectively (Knuttgen and Saltin, 1972; Sahlin, 1990). The magnitude of depletion may depend on factors such as muscle mass, O_2 stores (mainly from hemoglobin and myoglobin) and the relative intensity of exercise (Saltin, 1990). Parkhouse and McKenzie (1984) hypothesised that the state of an athlete's training appears to influence the rate of depletion of anaerobic energy stores (i.e., the more highly trained athletes were associated with slower rates of energy depletion). More specifically, the lowering of intracellular pH level which occurs with exercise had been associated with the inhibition of glycolytic enzymes. These enzymes are needed to augment anaerobic performance. Parkhouse and McKenzie (1984) postulated that the elite performances of sprint-trained athletes may be associated with an attenuation of the enzymatic and contractile properties of the muscle. They suggested that anaerobic training may improve the proton-sequestering capacity of buffers such as inorganic phosphate, protein-bound histidine residues, the dipeptide carnosine, bicarbonate, and creatine phosphate.

A positive relationship has been demonstrated between the relative percent of fast twitch fibres in muscle fibre distribution and high powered anaerobic performances of elite male, but not female athletes (Froese and Houston, 1987). Froese and Houston (1987) hypothesised that the lack of a strong relationship between the female athletes' fast twitch fibres and anaerobic power may have been due to inappropriately low resistance settings. The authors suggested that total depletion of the females' anaerobic energy stores may not have occurred. Stores of PCr were reported to be the same in all types of muscle fibre (Edstrom and Ekbolm., 1972), therefore characteristics of elite anaerobic performances may be found in other processes such as anaerobic glycolysis, enzymatic activity, or pH tolerance. The rate of glycogen depletion was recently reported to be approximately 30-35% lower in type I muscle fibres compared with type II fibres at supramaximal intensities up to 200 percent of maximal aerobic capacity (Vollestad et al., 1992). A significant relationship has also been reported between changes in plasma catecholamines and estimations of ATP production during 30 s of sprint running (Cheetham et al., 1986).

Section Summary

High intensity exercise draws on existing stores of ATP, PCr, and muscle glycogen. Higher initial levels of these combustive fuels have been associated with better performances and perhaps delayed onset of muscle fatiguing levels of metabolic acidosis. In comparison with the aerobic use of energy, the depletion of anaerobic energy stores is rapid. State of training, and the composition of fibre types within the muscle appear to also significantly contribute to anaerobic performance. Recently, investigations aiming to quantify and qualify anaerobic energy sources have been documented by Medbϕ and several co-authors (1987, 1988, 1989, 1990, 1991). This work will be discussed in more detail in the section which describes anaerobic testing. Saltin (1990) surmised that in spite of more than 50 years of experimentation on aerobic and anaerobic energy sources, many phenomena remain difficult to explain.

2. Specific anaerobic responses of children

Examining short, powerful bursts of energy may be far more relevant to researchers of pediatric populations than obtaining maximal or 'peak' oxygen uptake scores from long continuous bouts of exercise. Sargeant (1989) advocated that since children rarely operate at their maximal capacity, anaerobic studies were much more realistic for children than maximal endurance tests. Lower anaerobic performances of children compared with adults have been consistently reported in the literature (Bar-Or, 1987; Inbar and Bar-Or, 1986; Vandewalle et al., 1987; Zwiren, 1989). Even when expressed in relation to body mass, the anaerobic performances of children were inferior to adults (Bar-Or, 1983; Bar-Or, 1987; Inbar and Bar-Or, 1986; Sargeant, 1989). When compared with the available research on adults, there is a dearth of literature concerning anaerobic metabolism in children. This is because quantifiable measurements of the precise anaerobic mechanisms rely on analyses from biopsied samples of key enzymes and estimates of fuel depletion within the muscle. Very few invasive studies of muscle biopsies on healthy children exist within the literature (Bell et al., 1980; Berg and Keul, 1988; Eriksson et al., 1971; Eriksson et al., 1973; Haralambie, 1979). Table 2.1 summarises the findings of several invasive studies on children. More stringent ethical and moral guidelines exist for research in pediatric exercise science compared with research with adults (Jonsen, 1978; Rowland, 1989). Subsequently, often the discussion of children's inferior anaerobic performance has been restricted to postulations rather than support from empirical data.

Early research examining the poorer anaerobic performances of children when compared with adults was associated with findings of reduced levels of blood and muscle lactate (Astrand, 1952; Eriksson et al., 1971). Perhaps the most frequently cited invasive study on children is an investigation by Eriksson et al. (1973). In this study Eriksson et al. (1973) examined the effects of training on the skeletal muscle metabolism in eight 11-13-year-old males. Muscle biopsy samples from the vastus lateralis were taken before and after four months of training. The training over the four months was conducted three times a week and involved interval training, basketball, and soccer. Following the training, increases were reported in resting data of the children's glycogen levels (from 54 to 71 mmol glucosyl units·kg-1 wet wt, ATP (from 1.2 to 4.3 ATP mmol·kg^{-1} wet wt) and PCr concentrations (4.8 to 14.5 PCr mmol·kg^{-1} wet wt). Maximal exercise elicited higher blood and muscle lactate levels of 1.67 to 4.7, and 8.8 to 13.7 mmol (kg wet wt)$^{-1}$ before and after training, respectively, but ATP and PCr depletion rates remained unchanged. Muscle biopsies were also taken from another group of five boys who cycled for 30 minutes, three times a week over six weeks. When compared with adults, the male children were reported to hold similar aerobic power per unit of body mass. However, the anaerobic potential in the form of the glycolytic rate-limiting enzyme phosphofructokinase (PFK level after training was 15.41 μmol·(g·min)$^{-1}$) and blood lactate levels remained lower in children than adults even after training. It was noted that the activity of the PFK and the oxidative phosphorylation based enzyme, succinate dehydrogenase (SDH) increased significantly following training. The PFK levels of the five children were 50% less than the levels previously reported for adults and the SDH levels were 20% higher than those reported in adults (Gollnick et al., 1972). The study reflected higher concentrations of anaerobic activity indicators of lactic acid and PCr following training. It was also noted that the children did not demonstrate higher rates of ATP turnover and PCr depletion in post training assessments. However, one of the problems created by the frequently quoted work of Eriksson et al. (1973) could be that the invasive investigation was conducted on a relatively small sample size of five male children.

Berg and Keul (1988) examined the hypothesis that children in comparison with adults have a greater affinity for lipid utilization and a reduced capacity for exercise-related catabolic reactions, such as anaerobic glycolysis. The authors measured the muscle enzyme activity level from biopsy samples of the vastus lateralis muscle for aerobic and anaerobic energy sources in subjects aged from 4-18 years. The ratio of the enzymatic activities of fumarase (used in the TCA cycle for the conversion of malate to oxaloacetate) to pyruvate kinase (the energy yielding catalyst in the conversion of phosphoenolpyruvate to pyruvate in the final stage of glycolysis) was used as an index of aerobic to anaerobic predisposition. Younger children (4-8-years-old) recorded ratios which were approximately 100% higher than those found in adults. Thus, younger children demonstrated a greater potential for aerobic than anaerobic metabolism than adults.

Bell et al. (1988) reported slightly larger volume density in the mitochondria of 6-year-old children than adults and an increased level of intracellular lipids. This supports the aforementioned hypothesis of Berg and Keul (1988) of greater aerobic than anaerobic potential in children. Haralambie (1979) reported higher activity levels of the citrate cycle enzymes and the lactate dehydrogenase (LDH) enzymes in 11 to 14 year old girls in comparison with adults males. He postulated that the results had reflected higher habitual daily activity in children compared with adults and that this had directly influenced the muscle enzyme activity level. Lehmann et al. (1981) reported that norepinephrine levels in children were 30% less than adults during maximal exercise. Epinephrine levels in children were age-specific during maximal exercise. Berg and Keul (1988) supported the findings of Lehmann et al. (1981) and similarly suggested that poorer anaerobic performances in children compared with adults may well be related to a reduced sympathetic drive. Macek (1986) expanded this hypothesis to postulate that the reduced sympathetic activity of children during exercise caused less vasoconstriction of the vessels surrounding muscles which cleared the lactate to the liver for gluconeogenic processing in the Cori cycle. According to Macek (1986), it may well be that children produce just as much lactate as adults during exercise, but the levels were lower because of a more efficient lactate clearance mechanism. Mero (1988) reported that in short term high intensity work of prepubescent children aged 10-13 years, blood lactate levels correlated positively with muscle fibre area (type II%) and serum testosterone levels. Thus lactate levels may well be linked to the age-related increments observed in anaerobic performance. High serum lactate levels which were comparable to adults have been reported in children following maximal exercise exertion during treadmill running (Cumming et al., 1980). The difference here may be attributable to the fact that serum lactates rather than blood lactate levels were assessed. Saltin (1990) asserted that blood lactate was merely an indicator of glycolysis and should not be used to quantify anaerobic yield. Measuring blood lactate levels should not be accepted as representative of muscle lactate levels because of; variability in the dilution space into which the lactate may move, difficulties in quantifying the turnover rate and concerns with assumptions of consistency in the lactate samples within the same muscle and indeed the entire active muscle mass (Saltin 1990).

In a review of the biochemical changes during exercise in children Berg and Keul (1988) concluded that the relative aerobic power in children compared favourably to adults. The authors associated the relatively reduced anaerobic performances of children with lower levels of PFK and a lower glycolytic flux in the working muscle. Thus one of the underlying theories on the poorer anaerobic performance of children when compared with adults has been that children are much more aerobically predisposed and that the anaerobic capacity is immature. Improvements in anaerobic performances following one year of training in various sports by 19 males aged 10-12 years correlated positively with relative changes in testosterone (Mero et al., 1989). Recently Nazer et al. (1992) reported higher plasma ammonia levels in trained children than untrained. In relative terms however, both groups of children demonstrated reduced levels of plasma ammonia in children when compared with adults. The potential to gain higher biochemical reponses from children following training such as sprint running and swimming clearly warrants further investigation.

Poorer anaerobic performances of children have also been associated with peripheral respiratory adjustments. Zwiren (1989) linked a reported shorter half time to steady state oxygen uptake as one of the possible mechanisms which reduced anaerobic contribution metabolism in children. Implicit in the shorter half time to steady state is a faster predominance for aerobic rather than anaerobic mechanisms. Cooper et al. (1987) investigated coupling ventilation (V_E) and carbon dioxide (CO_2) production during the transition from rest to exercise in children 6-18 years of age. A small but significant decrease was reported in the V_E/VCO_2 ratio with body mass. Cooper et al. (1987) reported time constants (the time required to achieve 63% of the difference between baseline and the steady state VO_2 asymptote) for V_E and CO_2 were approximately 30% faster in younger children than adults. The end tidal partial pressure of CO_2 (PCO_2) was also lower in younger children than adults. The authors postulated that the PCO_2 may be regulated at lower levels in younger children and that there may be growth-related differences in the amounts of storage space which is available for CO_2 in children compared with adults. Poorer anaerobic performances of children have been further linked to maturational processes of respiratory control mechanisms during childhood. Springer et al. (1988) hypothesised that peripheral chemoreceptors contributed to a different respiratory tone in children when compared with adults. They concluded that the different responses in children from adults were mostly prevalent when children changed from hypoxic to hyperoxic conditions. A reduced sensitivity to hypoxia was postulated to decrease during maturation in children. In agreement with the findings of Cooper et al. (1987), Springer et al. (1988) suggested that the faster ventilatory responses of children compared with adults were associated with a reduced storage space for CO_2 which caused it to move quickly to add to PCO_2 and reach the central and pulmonary circulation faster in children.

The hypothesis of reduced storage space for CO_2 contributing to faster kinetics at the onset of exercise in children when compared with adults was further developed by Poage et al. (1987). A comparison was made between the V_E and VCO_2 responses of normal children to those of obese children. Theoretically larger children would like adults have a larger body size than "normal size" children. A greater body size was hypothesized to be associated with a greater storage capacity for CO_2 and a subsequent potential for a slower VCO_2 response. Preliminary investigations reported time constants for V_E and VCO_2 which were approximately 20% longer in obese children than "normal sized" children. Poage et al. (1987) also reported that these differences occurred without any change in the time constant for VO_2. Cooper (1989) speculated that the implied reduction in PaO_2 at the onset of exercise for obese children may result in discomfort from tissue hypoxia and may be further linked to a lowering of activity levels in this populations.

In addition to theories of reduced storage capacity, differences in the dynamic responses of VE and VCO_2 in children when compared with adults have also been associated with other factors. These included; reduced hemoglobin (and subsequent CO_2 transport mechanisms) of children, and differences in body composition which link increases in body fat to protein distribution with age to improved mechanisms for transport of CO_2 in its soluble form (Cooper, 1989).

Armon et al. (1991) hypothesised that the VO_2 response to high-intensity exercise would be different in children (aged 6-12 years) from adults (aged 27-40 years). It was concluded that the high-intensity exercise could be associated strongly with an oxygen drift phenomenon in adults. No oxygen drift was reported in over half the children at intensities greater than the anaerobic threshold (AT). Armon et al. (1991) associated the absence of an oxygen drift with the lower accumulated lactate mechanisms previously reported in children. The children in the study by Armon et al. (1991) also produced higher, less efficient ratios of VO_2 to work compared with adults. It was postulated that the greater metabolic cost of work in children may be indicative of a reduced ability of children to support anaerobic (O_2 sparing) mechanisms of ATP metabolism. Consistent with the aforementioned postulations of Macek (1986), Armon et al. (1991) linked the higher VO_2 to work ratios at all intensities in children to a greater ability to oxidise the lactate produced during exercise. Armon et al. (1991) reported faster time constants to steady state in children compared with adults. The authors speculated that this too may represent a reduced dependence on anaerobic responses at the onset of exercise in children than adults. The findings of Zanconato et al. (1991) did not support findings of faster time constants in children when compared with adults. The authors reported differences in the end of exercise O_2 costs in children compared with adults under highly intense exercise conditions. Zanconato et al. (1991) reported that the end of exercise O_2 costs in exercise decreased with intensity in adults, but in children the final O_2 cost remained stable but were also significantly higher than the adult group. Zanconato et al. (1991) also postulated that decreased anaerobic capacity in children compared with adults was associated with a greater aerobic dependence in children than adults.

Section Summary

There are several recurrent themes in the literature examining the lesser anaerobic performance of children when compared with adults. The possible causes for poorer anaerobic performances have been linked to a preference in children to meet energy demands from aerobic rather than anaerobic sources of energy. The mechanisms for the aerobic preference of children appear to be both metabolic and peripheral in nature (Table 2.1). These include; a greater ratio of aerobic to anaerobic enzymes, relatively larger mitochondrial volume in which to aerobically supply ATP, reduced sympathetic nervous activity, poorer storage capacity for CO_2 and the subsequent different O_2 cost and kinetics of children compared with adults during intense exercise.

Table 2.1: Summary of key invasive studies related to anaerobic responses of children

Authors	Year	Major metabolic findings
Bell et al.,	1980	• small increase in volume density of mitochondrial and intracellular lipid levels
Berg and Keul	1988	• age-related increase in glycolytic enzyme and ATP resynthesis activities • aerobic to anaerobic capacity expressed as the enzyme activity ratio of fumarase to PK**** was 100% higher in children than adults
Haralambie	1979	• habitual activity influences enzyme levels • higher citrate cycle enzyme activity • higher LDH*** activity in 11-14-year-old females compared with adult males
Mero et al.,	1989	• training-related increases in testosterone levels correlated with improvements in anaerobic performances.
Nazer et al.,	1992	• lower plasma ammonia levels in children compared with adults.

* PFK = phosphofructokinase

** HLa = blood lactate

*** LDH = lactate dehydrogenase

**** PK = pyruvate kinase

3. Testing anaerobic characteristics

a. Anaerobic power tests.

Vandewalle et al. (1987) divided anaerobic tests into two categories: anaerobic power tests and anaerobic capacity tests. Initially, tests were further divided into those seemingly testing alactic and lactic performances. However, this categorisation can be questioned in light of the findings of lactic acid production occurring very soon after the onset of exercise (Jacobs et al., 1983). Vandewalle et al. (1987) began a review of anaerobic tests with the anaerobic power tests. Vertical jumps, stair climbs, force-velocity tests and all-out cycling tests were categorised as anaerobic power tests. The results of these tests were significantly altered by different protocols. All-out cycling protocols have been used with fixed (Katch et al., 1977) and proportional braking forces (Ayalon et al., 1974). A substantial amount of literature is available on adults investigating the optimal testing conditions for the Wingate Anaerobic Test (WAnT) which is perhaps the most commonly used of all-out cycling test protocols (Table 2.2). For example, Inbar et al., (1983) examined the effects of varying crank length for optimal performance on the WAnT. La Voie et al. (1984) investigated the use of toe stirrups, and Evans and Quinney (1981) experimented with body composition characteristics being included in optimal resistance testing. In addition to this, McKenna, et al (1987) investigated the effects of several warm up protocols on the performance of supramaximal cycling tasks. Optimal testing conditions for child-based populations have also been suggested (Table 2.3). Inbar and Bar-Or (1983) recommended that children use an intermittent protocol during warming up prior to the WAnT. Klimt and Voigt (1971) elicited better performances from younger children with shorter crank lengths; however this study was based on submaximal aerobic performance. Recently, Elias et al. (1991) demonstrated that efficiency of cycling in light-weight children (26 to 47 kg in body mass) was not influenced by the use of shorter crankarm than the standard length of 17.5 cm.

A number of investigations have specifically examined the choice of resistance to be used in anaerobic cycling ergometer tests (Dotan and Bar-Or, 1983; Evans and Quinney, 1981; Gastin, 1992, Katch et al., 1977, Patton et al., 1985). Two existing publications provide summary tables of studies investigating the optimal resistances in WAnTs; Bar-Or (1987), Dotan and Bar-Or, (1983). However, anomalies are evident in between-study comparisons due to diversities in protocols, test duration, motivational strategies, and the nature of cycle ergometer used. Additionally, perhaps the greatest problem in determining the choice of resistance appears to be related to the specificity of the sample. Very few resistance choices have been broadly applied.

A study conducted by Dotan and Bar-Or (1983) investigated load optimisation for the WAnT anaerobic tests in 35 young males and females (24 and 20 years of age, respectively). Optimal performances were reported from resistances of 0.0667 and 0.0703 kp·kg·BM for females and males, respectively. Beld et al. (1989) investigated load optimisation for peak, and mean power output in WAnTs in three groups of males who were untrained, endurance trained and power-trained. Tests were performed in 0.006 kg increments from 0.075 to 1.05 kp·kg·BM. The authors reported no significant differences among the responses in the groups of athletes and hypothesised that significantly greater and 'optimal' performances may in fact be obtained from resistances beyond the 1.05 kp·kg·BM resistance.

The original WAnT had prescribed a resistance of 0.075 kp·kg·BM (Ayalon et al., 1974); however, subjects in this study were non-athletic young adolescents. Dotan and Bar-Or (1983) recommended a resistance of approximately be 0.0703, and 0.0667 kp·kg·BM for 13-14-year-old males and females, respectively. Weijiang and Juxiang (1988) used the results of WAnTs performed by 11-18-year-old children and adolescents to recommend the use of 0.075 kp·kg of lean body mass instead of the more commonly cited 0.075 kp·kg·BM .

In more recent studies by Van Praagh et al. (1989) and Van Praagh et al. (1990), peak power performances were obtained from 7 and 11-year-old children in individual performances of a series of incremental tests along a force velocity curve. Resistance increments began at 0.5 kp and increased until no further improvement in peak mechanical power was observed. Once the resistance eliciting peak performance over a short period of time in the child was identified, it was then used in performance in the WAnT. It was concluded that for the 7-year-old males in the study, the optimal resistance for peak performance was obtained against approximately 0.064 kp·kg·BM. In a later publication with 11-year-old males and females, Van Praagh et al. (1990) reported that resistances of 0.085 and 0.068 kp·kg·BM could be associated with peak performances on the WAnT of the males and females, respectively. Van Praagh et al. (1990) also surmised that when peak, and mean power results were corrected for lean thigh volume, males performed significantly better than the females. Vandewalle et al. (1987) postulated that the original load application of 0.075 kp·kg·BM may be most applicable to child-based populations in WAnTs. However, both Bar-Or (1987) and Vandewalle et al. (1987) subsequently suggested that the choice of resistance remained unresolved and have recommended that more research was necessary in this area.

Table 2.2: Previous literature on anaerobic testing modifications for cycling ergometer tests.

Authors	Group	Nature of investigation	Recommendations
Craig et al., 1989	adult male cyclists	varying test durations	event specificity needed (i.e., approximately 60s)
Evans and Quinney, 1981	trained adult males	resistance	body mass and leg volumes were best determinants
Inbar et al., 1983	adult males	crank lengths	standard length = 17.5 cm
Katch et al., 1977	adult males	resistance and duration	resistance = 5-6 kp duration = 40s
La Voie et al., 1984	adult males	use of toe stirrups	significant improvements with toe stirrups
McKenna et al., 1987	adult males	warm up protocols	improved performances with warm ups protocols with intervals did not make a difference
Sargeant et al., 1984b	adult males	% fibre type and revolution rate	>50% Type II = 119 rpm <50% Type II = 104 rpm
Vandewalle et al., 1987	adult males	body position	15% improved performance from standing rather than sitting

Table 2.3: Previous literature on anaerobic testing modifications for cycling ergometer tests in children.

Authors	Group	Nature of investigation	Recommendations
Inbar and Bar-Or, 1975	children	intermittent warm ups	intermittent warm up was significantly superior to others
Klimt and Voight 1971	6-10-yr-old children	crank length	13 cm for 6-year-old children 15 cm for 8-10-year-old children
Sargeant et al., 1984a	13.7-yr-old children	revolution rate	110 rpm (same rate in children as adults)
Van Praagh et al., 1990	11-year-old children	resistance and body composition	0.068 kp·kg·BM for girls 0.085 kp·kg·BM for boys LTV* associated with girls FFM** associated with boys

*LTV lean thigh volume

**FFM fat free mass

The reliability of the WAnT has also been documented in the literature available. Bar-Or (1987) reported that the correlation coefficients for the WAnT under standardised conditions ranged from .89 to .98 with most values consistently higher than .94. Bar-Or (1987) also claimed that higher reliability values could be expected from the mean, rather than peak power measurements. Repeatability values for the peak and mean power of .94 and .98, respectively were also reported by Bar-Or (1987) from tests with disabled children. Other studies have reported higher correlation coefficients in mean power than peak power. With the aid of computer precision, a basket arrangement for the loading of the flywheel, a rolling start, and a standardised warm up, peak and mean power repeatability values were reported by Parry-Billings et al. (1986) to be as high as .94 and .89, respectively.

The amount of experimental or technological error is not immediately evident from repeatability tests (Katch et al. 1982). Obtaining a coefficient of variation over several trials provides a better indication of the extent of variation in an experimental method. Katch et al. (1982) partitioned the variability or mean coefficient of variation into biological (experimental) and technological variability. The total variability of the group was the averaged value of individuals' scores on more than two tests when the mean value was divided by the standard deviation (C.V. = S.D./X x 100). Technological error sources were determined from a series of calibration studies on factors identified as potential error sources of a non environmental, equipment-based nature. Technological errors were regarded as relatively constant. Biological error sources were then identified as the remaining percentage of the total variability when the technological error factor was subtracted. Katch et al. (1982) investigated the biological variability of maximal aerobic power of five adults. The total variability was 5.6%. It was estimated that the technological variability of the results accounted for 10% of the total variability and that the remaining 90% was due to biological variability. Coggan and Costill (1984) obtained the coefficient of variation from anaerobic performances during three cycle ergometer tests. The authors randomly assigned 27 male adults to three groups who performed a tests on an isokinetic cycle ergometer (a FITRON™) These tests involved either a FITRON™ 30 s all-out cycling test, a FITRON™ 60 s all-out test, or a timed ride to exhaustion at 125% of maximal effort. The subjects performed four trials over a four to five week period. Analysis of variance revealed no significant within-group differences for the tested variables. Total mean coefficients of variation for peak, and mean power, and fatigue index on the 30 s anaerobic test were 6.7, 5.4, and 10.3%, respectively. From the total variability scores, the percentages of technological error were identified for peak and mean power, and fatigue index as 15.7, 18.2, and 4.5%, respectively. These results demonstrated that the greatest biological variation error factors were identified within the fatigue index measurements.

A study from Sargeant et al. (1981) was one of the first published on power tests from performances on isokinetic cycle ergometers. It was reasoned that the use of isokinetic devices would, in theory accommodate alterations in acceleration and deceleration during testing and would, if performed over short periods of time provide a truer indication of maximal power than other types of cycle ergometers. It was also reported that the recommended speed at which optimal power performance was obtained in children occurred between 110 and 120 rpm on isokinetic cycle ergometers. Sargeant (1989) expressed concern with the common practice of reporting power performance results in relation to body mass. Sargeant (1989) suggested that children's data be normalised to the dimensions of the active muscle. The author recommended that until intrinsic characteristics of children's muscles can be identified through nuclear magnetic resonance (NMR) or other precise non invasive mechanisms, then anthropometric measurements taken on 'truncated cones' of the limb segments must be considered as a more equitable measurement than expressing performance in relation to body mass. For example, Sargeant (1989) reported a correlation coefficient of .96 on the linear regression for the anterior thigh skinfolds and power performances of children aged 6-15-years. However, Sargeant (1989) acknowledged that anthropometric measurements failed to distinguish between the role of the agonist and antagonist muscle of the exercising limb segment. Precision in quantifying the amount of active muscle mass appears to present a large challenge to researchers.

Summary

Much research has been conducted in pursuit of the ideal testing of short term power performances of humans. Numerous protocols have been published, yet anomalies still remain because of diversity and inconsistency in the population tested, equipment used and methods applied. Work in pediatric populations on the suitability of short term power tests has to date not been fully explored.

b. Anaerobic capacity tests

Medbϕ (1991) describes anaerobic capacity as the maximum amount of ATP that can be regenerated under anaerobic exercise conditions. Anaerobic ATP resynthesis occurs predominantly from the breakdown of PCr and the production of lactic acid via anaerobic glycolysis. Given the known limits to stores of CPr and maximal tolerance levels of lactic acid within the muscle, measuring an anaerobic capacity appears a valid scientific pursuit.

Many of the currently practised short-term tests for anaerobic characteristics have recently been criticised for an inability to completely exhaust the capacity of the anaerobic system. Saltin (1990) and Withers et al. (1991) argued that substantial amounts of anaerobic energy supplies still exist after the short term power tests of 30 s or less. Withers et al. (1991) found increasing muscle lactate levels (19.0, 25.2, and 25.7 $mmol{\cdot}(kg\ wet\ wt)^{-1}$ and decreasing PCr levels (4.40, 3.37, and 3.54 $mmol{\cdot}kg^{-1}$ wet wt) following 30, 60, and 90 s of exhaustive cycling, respectively. Methods of determining the anaerobic capacity in man have been discussed thoroughly in the literature (Saltin, 1987). A summary of Saltin's review (1990) has been presented in Table 2.4. This section on anaerobic capacity tests has concentrated on the determination of anaerobic capacity from a method known as the maximal accumulated oxygen deficit (AOD). Krogh and Lindhard (1919) first introduced the concept of O_2 deficit as the transition phase of respiration and circulation at the onset of exercise. O_2 deficit was described as the oxygen uptake system's adjustment phase to increased work demands. Medbϕ (1991) accredits Karlsson (1971) as being the first researcher to measure O_2 deficit from an extrapolation of submaximal responses. However, rather than determining precise efficiency demands throughout the series of submaximal steady state increments, Karlsson (1971) assumed a fixed efficiency of 0.225 for all exercise intensities for all subjects.

Hermansen and Medbo (1984) introduced the method of obtaining maximal O_2 deficits from individual responses to steady state submaximal exercise and extrapolating the established power-O_2 relationship into supramaximal exercise intensities. Jon Medbϕ has since provided an impressive depth of research on the validity of the accumulated oxygen deficit method as a means of obtaining maximal anaerobic capacity (Medbϕ, 1991; Medbϕ et al., 1988; Medbϕ and Tabata, 1987; 1989). Rather than expressing anaerobic capacity as a rate, Medbϕ et al. (1988) chose to express it as an amount of energy; in litres or $ml.kg^{-1}$ for the duration of the test. The term accumulated refers to measurements predicted or taken over the duration of the test. Accumulated oxygen deficit is measured as the difference between the predicted (theoretical) oxygen demand and the actual oxygen uptake of a supramaximal exercise bout. The prediction is calculated by an extrapolation from the linear regression of power and O_2 within a series of submaximal oxygen uptake exercise bouts. According to Medbϕ (1991) the precision of the method is approximately 4%. He claimed that 90% of the variance in the error factor was attributed to imprecision in estimating the O_2 demand from linear extrapolation. In the accumulated oxygen deficit the scatter around the regression line should be minimal. In other studies where the accumulated oxygen deficit has been used, the resulting linear regressions have all had correlation coefficients greater than .99 (Bangsbo et al., 1990; Gastin, 1992; Graham and McLellan, 1989; Withers et al., 1991).

c. Criteria for capacity in the accumulated oxygen deficit method

Medbϕ et al. (1988) and Medbϕ (1991) strongly defended the validity of the accumulated oxygen deficit method as a means of identifying the capacity of the anaerobic energy sources in the body. Medbϕ et al (1988) set out the three criteria which, if supported would confirm the presence of maximal anaerobic work. The first criteria centred on the need to observe some degree of levelling off. or plateauing in accumulated oxygen deficit scores under supramaximal conditions. Medbϕ et al. (1988) reported that accumulated oxygen deficits and blood lactates continued to increase in supramaximal tests lasting up to 120 s. A plateau occurred beyond 120 s of supramaximal treadmill running, which suggested that a capacity had been reached. Pate et al. (1983) similarly reported a plateau effect in the accumulated oxygen deficits obtained from cycling at 110, 120, and 130 relative percent of maximal aerobic uptake. Test durations however, were not reported.

Gastin (1992) investigated the accumulated oxygen deficit in eight male adult subjects (mean age of approximately 22 years) during supramaximal tests of 45, 60, and 90 s. A significant difference occurred in the accumulated oxygen deficits between the shortest and longest tests (47.6 and 49.6 $ml.kg^{-1}$, respectively). Gastin (1992) demonstrated that maximal accumulated oxygen deficits could be obtained within 60 s of supramaximal exercise on a cycle ergometer. It was reported that after 60 s no significant increases in accumulated oxygen deficits occurred among tests conducted at 110, and 125% of peak oxygen uptake in a constant power mode and

Table 2.4: Summary of methods for determining anaerobic capacity

Method	Problems
Blood lactate after exhaustive exercise (Margaria et al., 1963)	• identifying the point of equilibrium between muscle and blood lactate concentration • variability of dilution space • high turn-over rate of lactate
Oxygen debt - estimated lactate activity to equal oxygen deficit (Christensen and Hogberg 1950)	• accounting for the energy yield for lactate to provide glucose synthesis • estimating amounts of oxidized lactate and recognition that factors other than lactate elevate the oxygen consumption in the body after exercise
Extrapolating O_2 deficit from submaximal conditions (Karlsson (1971)	• assuming constant and equal 25% efficiency for all subjects at all submaximal intensities
Accumulated O_2 deficits from submaximal tests extrapolated into supramaximal levels (Medbϕ et al., 1988).	• difficulties with the assumption that mechanical efficiency from submaximal to supramaximal conditions (likely to underestimate)

an all-out protocol in an isokinetic mode. Withers et al. (1991) also achieved maximal accumulated oxygen deficits and maximal blood lactate values within 60 s of all-out exercise on an air-braked cycle ergometer. It may be surmised that the originally suggested 120 s of time before a plateau occurred in accumulated oxygen deficit (Medbϕ et al., 1988) may have differed from the above mentioned studies because Medbϕ et al. (1988) used a treadmill and the other studies used cycle ergometers to elicit supramaximal performances.

The second criteria for the validity of the accumulated oxygen deficit method addressed the independence of the maximal aerobic and anaerobic energy systems. From experiments conducted under supramaximal conditions, Medbφ et al. (1988) reported significantly reduced maximal oxygen uptake performances under hypoxic conditions. However the hypoxic conditions made no significant difference to anaerobic capacities obtained by the accumulated oxygen uptake method. Thus, Medbφ et al. (1988) were satisfied that the maximal accumulated oxygen deficit method had complied with the second criteria for validity.

Directly quantifying the accumulated oxygen uptake method requires accurate knowledge of the amounts of anaerobic energy released and of the proportions of working muscle mass involved in the exercise. Values from muscle biopsy samples are assumed to be representative of the whole muscle and in fact, the entire working muscle mass. One method of measuring anaerobic ATP turnover rate has been to measure pre and post exercise differences in the muscle lactate and creatine phosphate concentrations. Medbφ (1991) believed that to date, no generally accepted methods exist for measuring the direct turnover rate of ATP during exercise. In spite of these methodological constraints, the third criteria for acceptance of anaerobic capacity suggested by Medbφ et al. (1988) was that data obtained for accumulated oxygen deficits under non invasive conditions needed to be in agreement with values from muscle biopsies documented in previous research. At the completion of the study, the authors were satisfied that their estimations of the energy contributions from blood lactate, and muscle phosphocreatine and lactate levels following exhaustive exercise were in agreement with those published previously. Additionally Medbφ et al. (1988) were able to tabulate the relative energy contribution sources to account for obtained energy equivalents in the accumulated oxygen deficits in their subjects.

d. Basic assumptions behind the accumulated oxygen deficit method

Medbφ et al. (1988) further defended the two basic assumptions on which the accumulated oxygen deficit method was based. The first assumption is that oxygen demand was constant during supramaximal exercise. Medbφ et al. (1988) firstly argued that oxygen demands in the first few minutes of exercise such as ATP formation from anaerobic sources and lactate formation were constant in the oxygen deficit phase for both aerobic and anaerobic workloads. Medbφ et al. (1988) argued that in constant power tests, if the intensity was constant, so too was the rate of energy release. From a study of the submaximal responses to one hour of constant exercise, Medbφ (1991) reported that a 5% shift in oxygen uptake was more closely associated with a change from carbohydrate to fatty acid oxidation during exercise, than a change in the ATP turnover rate. Medbφ (1991) believed that in constant exercise demand even under supramaximal conditions, the ATP turnover rate would remain constant even over extremely short periods of time. However, Medbφ (1991) did acknowledge that the experimental evidence was taken from submaximal data and that accepting this as evidence for higher intensities may not be appropriate.

One of the biggest challenges to the accumulated oxygen deficit method is the second assumption, that supramaximal exercise economy can be assumed to be a linear function of submaximal exercise economy. Saltin (1987) suggested that the lowest mechanical efficiencies were found at the highest relative intensities and therefore the true energy costs of supramaximal exercise were likely to be underestimated. Saltin (1987) could not accept that the energy costs could be extrapolated from submaximal to supramaximal conditions. He believed that supramaximal exercise conditions incurred much more oxygen than could be predicted from submaximal conditions. Saltin et al. (1972) reported 16-19% efficiency instead of 20-25% efficiency from subjects cycling close to maximal effort intensities. Given that supramaximal conditions were therefore much more inefficient than submaximal conditions, Saltin (1987) postulated that any extrapolation of supramaximal energy demands from submaximal conditions would grossly underpredict the true oxygen costs of highly intense exercise conditions. Medbφ (1991) however, challenged the very concept that anaerobic work was less efficient than aerobic work. The challenge was built on the knowledge that the early research on anaerobic energy release had been estimated from excess post-exercise oxygen consumption (EPOC) tests. Medbφ (1991) reasoned that EPOC following supramaximal exercise included non-metabolic factors which masked the true metabolic oxygen costs during anaerobic exercise. Medbφ (1991) hypothesised that the myosinATPase and other ATP sinks within the muscle, split ATP in only one way and could not discriminate between how it was supplied (i.e., from aerobic or anaerobic sources). Medbφ and Tabata (in review) further challenged the concept that efficiency changed with muscle fibre type recruitment. The authors (in review) investigated the mechanical efficiency in exercise ranging from 30-90% of maximal aerobic power. Based on the work of Gollnick et al. (1973, 1974) it was argued the during exercise of low intensity there would be a predominance of slow twitch fibres (type I) and during high intensity exercise there would be a predominance of fast twitch fibres (type II). Medbφ and Tabata (in review) and Medbφ (1991) asserted that if type I fibres were more efficient than type II fibres, then people with a predominance of type I fibres would be significantly more efficient than people with a predominance of type II fibres. Medbφ and Tabata (in review) could not support this assumption. It was further reasoned that if type I fibres, recruited at low intensity exercise were more efficient than type II fibres, recruited at higher intensities, then the power-O_2 relationship at higher intensities would be significantly more erroneous than deviations incurred at lower intensities. Again, the assumption could not be supported from their research. Medbφ (1991) extended the notion of efficiency not being related to fibre type recruitment with the finding that in prolonged exercise where there is a gradual shift from type I to type II muscle fibre recruitment, oxygen uptake remains consistent. More recently, Vollestad et al. (1992) reported that at intensities up to approximately 200 percent of maximal aerobic uptake, both type I and type II fibres were contributing to the total anaerobic energy release. Therefore Medbφ (1991) has defended the criticism of possible deviations from a linear extrapolation into supramaximal exercise, but has done so predominantly from a muscular efficiency perspective. Efficiency during highly intense exercise may well be affected by functional adjustments outside the muscle, such as energy demands from the cardiorespiratory system responding to the added work of stabilizing muscle of the upper body under highly intense conditions and the thermoregulatory mechanisms adjusting for increased demands from a rise in muscle temperature. Catecholamine activity may also increase the energy demand more under supramaximal than submaximal exercise conditions (Powers and Howley, 1990). Ahlquist et al., (1992) recently investigated the effect of pedaling frequency on glycogen depletion rates in type I and type II quadriceps muscle fibre during cycling under submaximal conditions. In this study the subjects were required to maintain 85% of VO_2 max by pedaling at either 50 rpm or 100 rpm. For cycling at the same metabolic cost, glycogen depletion was greater in type II fibres at 50 rpm than 100 rpm. This result was associated with the increased muscle force required to meet the demand at the slower pedaling frequency. It also has implications for the on-going debate of the stability of efficiency under submaximal and supramaximal exercise conditions.

Efficiency responses to exercise are closely linked to oxygen kinetics. Cooper (1989) recently reviewed three phases in the response to exercise. Phase one was termed the cardio dynamic phase because it denoted a rapid oxygen uptake increase during the first 20 s of exercise. Phase two was described by the exponential equation $VO_2(t) = VO_2(ss).(1-e^{-t/r})$. $VO_2(ss)$ is the difference between resting VO_2 and $VO_2(ss)$ and r is the time constant (i.e., the time elapsing to achieve 63% (1-1/e.100%) of submaximal steady state exercise). The t is a characteristic of the equation and is mathematically determined. Increases in cardiac output and $(a\text{-}v)O_2$ difference are denoted by Phase 2. Phase 3 identifies a constant power input during steady state. VO_2 is dependent on the consistency of power output over time. At higher work intensities (i.e., above AT) it may take longer to achieve steady state, or it may not be achieved. In adults performing exercise above the AT complex responses may occur and O_2 may rise rather than reaching steady state. It was speculated that this phenomenon was associated with additional oxygen requirements, such as oxygen for metabolising excess lactate that accompanies the harder work intensity during exercise. However, Roth et al. (1988) challenged the concept that lactate was principally associated with elevated VO_2 during the recovery phase of exercise. The results of Roth et al. (1988) suggested that removal of an experimentally induced large mass of lactate during recovery from exercise did not result in elevated VO_2. These authors postulated that factors more directly linked with the rate of mitochondrial respiration would be catecholamines, thyroxine, glucocorticoids, fatty acids, calcium and temperature. They suggested that the most important of the calorigenic factors could be temeperature as the rate of decline in post exercise temperature and post exercise VO_2 had been shown to be in parallel. The extent to which response patterns in VO_2 following exercise replicate those influencing VO_2 at the onset of exercise remains uncertain. What is apparent, is that the inital phases of highly intensive exercise induces non steady state conditions. These conditions may undermine the necessary requirements in the accumulated oxygen deficit method for the extrapolation of metabolic efficiency into supramaximal exercise.

The possibility of decreasing efficiency with increasing work intensity warrants further discussion. The phenomenon of gradual increases in oxygen uptake under steady state condition has been termed the oxygen drift (Hagberg et al., 1978). Several studies have examined the oxygen kinetics of intensive short term exercise (Cerretelli and Di Prampero, 1987; Roston et al., 1987; Whipp and Ward, 1990). Henson et al. (1989) examined the oxygen kinetics in subjects who completed a series of constant load tests above and below the lactate threshold. Henson et al. (1989) concluded that for tests above the lactate threshold there was an additional "slow phase" increase in oxygen uptake. This trend was apparent in trained and untrained subjects. The state of training however, has been reported to negatively effect oxygen drift in workloads between the anaerobic threshold and VO_2 max (Casaburi et al., 1989). It should also be noted that in an aforementioned study, (Armon et al., 1991) oxygen drift could not be reported in all of the children who exercised at high intensity. The work of Henson et al. (1989) was largely supported in a later publication by Whipp and Ward (1990). In non steady state exercise above the lactate threshold, the oxygen kinetics differed from the sublactate threshold steady state exercise in three ways: (a) The time course of oxygen uptake for suprathreshold exercise was slower than the time course observed during subthreshold, (b) there was a further and additional slow component of oxygen uptake during the onset of suprathreshold exercise (with Ward and Whipp (1990) remaining uncertain about the mechanisms behind this added phase), and (c) the described slow components of oxygen kinetics during supramaximal exercise consequently augmented oxygen uptake. The oxygen costs and kinetics were reported to occur at levels beyond which subthreshold predictions of suprathreshold oxygen costs could be accurately estimated. Whipp and Ward (1990) believed that oxygen kinetics was an area which would continue to be poorly understood until more sophisticated equipment could be used.

Medbo et al. (1988) conducted several series of pre-tests to defend the validity of the AOD method. From the results of these tests Medbo and co-workers (1988) could not support the assumption of greater than predicted oxygen demands under higher intensity exercise. Medbϕ (1991) observed that a greater number of deviations from the power-O_2 relationship occurred at high frequency cycling during lower rather than higher exercise intensities. Gastin (1992) hypothesised that the accumulated oxygen deficit method could inherently account for changes in efficiency within the process of measuring efficiencies for each incremental bout of steady state exercise in the power-O_2 relationship. High intensity steady state data would therefore be critical to the precision of the method. Nevertheless, several authors have also indicated other possible sources of the underestimation of supramaximal oxygen demands from extrapolations of submaximal exercise responses (Gastin, 1992; Gladden and Welch, 1978; Withers et al., 1991). These authors have discussed additional oxygen costs in supramaximal exercise from the work of stabilizing muscles, added stresses on the cardiorespiratory system, and possible changes in substrate utilization. Medb ϕ (1991) has been impressive in his evidence for the stability of 'in situ' muscle efficiency in supramaximal conditions, however the focus of this defence remains at the muscular level and does not include the possibility of increase O_2 demand from other sources within the body under highly intense exercise conditions. The discussion on the ability to extrapolate from submaximal to supramaximal conditions remains open to debate (Bangsbo, 1992).

e. Accounting for accumulated oxygen deficit from invasive studies

Several authors adjusted estimates of oxygen deficits for the presence of oxygen stored within the body (Bangsbo et al., 1990; Medbϕ et al., 1988; Saltin, 1987). Oxygen is stored within the body as components of blood, other body fluids, or within the lungs. In a 77 kg adult male, the estimate of stored oxygen's contribution to the accumulated oxygen deficit was 6 $ml.kg^{-1}$, with the majority of this being derived from oxygen saturation stores in the mixed venous blood (Medbϕ et al., 1988). In the work of Medbϕ et al. (1988), this amount was subtracted from the accumulated oxygen deficit scores and added to the accumulated oxygen uptake values. Medbϕ et al. (1988) acknowledged that this contribution was small in comparison with approximately 90% of the accumulated oxygen deficit scores incurred from anaerobic ATP formation. Saltin (1987) further examined the components of oxygen deficits from a compilation of invasive research data. The relative percent contribution of oxygen stores, phosphagen breakdown, and glycolytic processes to the oxygen deficits were 10, 30 and 60 in sedentary subjects and 6, 19, and 75 in trained subjects, respectively. Bangsbo et al. (1990) also examined the components of oxygen deficit during one-legged dynamic exercise from the extrapolation of the power-O_2 relationship obtained under steady state conditions. Muscle biopsies taken from the eight subjects in this study provided quantitative estimates of the cost of intense exercise. Bangsbo et al. (1990) estimated that pulmonary and leg oxygen deficits would represent approximately 0.46, and 0.48 litres·kg·active muscle^{-1}, respectively. The estimated amount of ATP formed during the supramaximal leg exercise was 94.7 mmol ATP (kg·wet wt^{-1}). This amount was accounted for from estimates of ATP-PC breakdown, lactic acid production, accumulation of glycolytic intermediates, and the unloading of O_2 stored in the body. Bangsbo et al. (1990) did not believe they could assume a consistency in the magnitude of anaerobic ATP production in human muscle throughput the body, so the results of this study were not interpreted as representative of the whole body. Medbφ et al. (1988) combined several studies to examine the relative contribution of the components of the accumulated oxygen deficit for whole body responses. The authors reported that oxygen stored in the body, high-energy phosphate stores in the muscle, lactic acid in the muscle, and lactate transferred to blood and ECF accounted for 9, 24, 51, and 16 % of the contributing factors to accumulated oxygen deficit, respectively. These values were verified by comparisons with previous investigations by Gramvik, (1991). Medbφ (1991) acknowledged that until exact proportions of working muscle mass could be identified, problems with the quantification of the oxygen deficit would remain unresolved.

Within the estimated total accumulated oxygen demand, measurements of accumulated oxygen uptake allow investigators to report the relative contributions of aerobic and anaerobic energy sources. Medbφ and Tabata (1989) examined the results of exhaustive bouts of cycling on a Krogh-type cycle ergometer lasting 30 s, 1 min, and 2-3 min and demonstrated relative contributions within the total energy supplies from aerobic sources of 30, 47, and 65%, respectively. Recently, Withers et al. (1991) used an air-braked cycle ergometer to exhaust cyclists in 30, 60 and 90 s. The relative contributions of aerobic sources to total energy supplies were 28, 49 and 64%, respectively. It should be noted that Withers et al. (1991) did not adjust for the approximated stores of oxygen in the body. Nevertheless, both studies indicated the relative aerobic contribution increases with exercise duration and conversely, decreases with exercise intensity. Both studies also demonstrated that even in 30 s of intensive exercise the contribution of aerobic energy sources appears to have been substantial. Medbφ (1991) asserted that although anaerobic processes predominated in exercise bouts of up to 1 minute duration the contribution from aerobic sources to short term exercise bouts had to date been underestimated. After approximately 1 minute, (not 2 minutes as had previously been advocated by Astrand and Rodahl, 1986) the contributions from aerobic and anaerobic sources were relatively similar (Medbφ and Tabata, 1989). Medbφ (1991) demonstrated for exercise bouts lasting up to three minutes, that Astrand and Rodahl (1986) had consistently over estimated the contribution of the anaerobic system. Astrand and Rodahl (1986) were reported to have based their estimates of the anaerobic contribution to exercise on EPOC data. Lactate and oxygen deficit data from Withers et al. (1991) strongly supported the concept that an intensive exercise bout of only 30 s duration, such as the WAnT was inadequate for exhausting the capacity of anaerobic energy. Muscle lactates of 19.0, and 25.2 mmol (kg wet wt)$^{-1}$, and oxygen deficits of 3.18 and 3.73 ml.kg^{-1} were reported for exercise bouts of 30 and 60 s, respectively. Withers et al. (1991) reported peak oxygen deficit and muscle lactate data following

60 s of exhaustive cycling. Again the data from Withers et al. (1991) did not support the previous contentions that anaerobic performances can be assessed in 30 s and that the anaerobic contribution to high intensity exercise was optimal after approximately two minutes.

f. Rates of accumulated oxygen deficit release.

An investigation into the rate of energy release (Medbφ and Tabata, 1989) complemented research into the relative contribution of energy sources during supramaximal exercise. The quotient of accumulated oxygen demand, deficit, or uptake, and test duration provides the rate at which each of these amounts of energy were released. Medbφ and Tabata (1989) demonstrated that the rate at which energy was released was closely related to test duration and more importantly the power of the test. The rates of release of the oxygen demand and oxygen deficit were highest with tests demanding the greatest power. Tracing the rate at which oxygen demand and oxygen deficit decreased with duration most appropriately fitted a hyperbolic curve. Conversely, the rate of release in oxygen uptake was lowest under the highest intensity tests and the rate increased with duration. Some controversy exists over whether or not the rate of anaerobic energy release is a reflection of training status and, or one of the limiting factors in test duration.

g. Training potential of the accumulated oxygen deficit.

Saltin (1990) reviewed the causes of exhaustion and lactate levels within the muscle and subsequently identified a number of potential events within the muscle, their limitations, and potential adaptations to training. Concomitantly, Saltin (1990) postulated that there were two main ways to improve the anaerobic capacity of an athlete. The first method would involve training for an improvement in the rate of glycolytic energy release through very intense, very short-term exercise bouts, and the second would be to train over somewhat longer periods of time for improvement in lactate tolerance within the muscle and its related pathways with predominantly longer time duration in the anaerobic activities. Medbφ and Burgers (1990) provided cross-sectional and short-term longitudinal data on training profiles of a number of adults. The cross-sectional profile of the subjects tested demonstrated that sprint athletes had accumulated oxygen deficit values which were approximately 30% higher than endurance-trained and sedentary subjects. The authors attributed these differences to factors of training and, or genetics. The training study divided the sample into two groups which closely resembled the scenarios described by Saltin (1990); one group trained to specifically improve the rate of anaerobic energy release and the other group trained to improve overall anaerobic capacity. Both groups undertook running training three times per week for six weeks. The group training for anaerobic energy release ran eight sets of 20 s at intensities individually designed to fully exhaust the subjects within 35-40 s. The group training for anaerobic capacity ran three sets of two minutes at speeds individually designed to exhaust subjects within 3-3.5 minutes. Training improved the maximal accumulated oxygen deficit of both groups of subjects by 10% (approximately 4.48 ml·kg^{-1}) (p=.008). The fundamental finding of the study was that no significant differences occurred between results from the two training methods. Medbϕ and Burgers (1990) postulated that the two characteristics of rate of anaerobic energy release and anaerobic energy capacity were closely related and may share common limiting factors. The authors also suggested that training results may have been different if alternative intensities had been applied. Medbϕ and Burgers (1990) used male and female subjects in their study. Pre-program testing revealed that accumulated oxygen deficits were 17% less in females than males. Following six weeks of training the improvement in the accumulated oxygen deficits of the females was not significant. The authors were inconclusive about the differing training effect in females compared with males. A more recent six week training study on swimmers demonstrated significantly greater improvement in the accumulated oxygen deficits of the sprint-trained (from 2.47 to 3.23 litres) than endurance-trained (from 2.65 to 2.64 litres) swimmers in pre and post program testing, respectively (Troup et al., 1991).

The study by Medbϕ and Burgers (1990) demonstrated significant differences between maximal accumulated oxygen deficits of sprint-trained and endurance-trained athletes. Saltin (1990) estimated assumed oxygen deficits in endurance athletes of approximately 80 ml "O2 Eq-kg^{-1}BM who were also likely to elicit maximal aerobic performances of approximately 80 ml·kg·$^{-1}$min^{-1}. He further estimated that in an elite "anaerobically" trained athlete performing an event (such as a 400-800 m run) an oxygen deficit of 100-120 ml O_2 Eq-kg^{-1}BM could be elicited. He stipulated that this large anaerobic capacity could only be possible where approximately 40% of total body mass was represented by muscle mass, and that the muscle mass was wholly activated by the athlete. However, Saltin acknowledged that the feasibility of using all muscles in the one exercise bout was somewhat unrealistic. Medbϕ (1991) also acknowledged the strong relationship between anaerobic capacity and power. He speculated that the subjects with the largest active muscle mass may also register the largest anaerobic capacity. Terrados et al. (1991) recently reported lower oxygen deficits in elite kayakers than could have been theoretically postulated from the estimations made by Saltin (1990). Maximal accumulated oxygen deficits in the kayakers were reported to average 45.91 ml O_2 Eq.kg-1. The smaller results from kayakers were associated with relatively less amount of active muscle mass during exercise than athletes such as sprinters whose active muscle mass is somewhat larger. The effect of the size of the active muscle mass on anaerobic capacity was also manifested in the measurement of the accumulated oxygen deficits from the same elite male swimmers performing different swimming strokes (Barzdukas et al., 1991). Accumulated oxygen deficits of 2.47 and 2.77 litres were elicited during performances at 110 relative percent of maximal accumulated oxygen uptake in tests of freestyle and breastroke, respectively. The authors concluded that anaerobic energy release during swimming was commensurate with the size of the participating muscle mass. Olesen (1992) reported significantly greater accumulated oxygen deficits from adults running at 15 and 20% than at a 1% incline when AOD tests were conducted on the treadmill. The amount of active muscle mass invovled was rejected as the most possible explanation for these differences. Olesen (1992) believed that predictions made from submaximal tests conducted at 1% incline on the treadmill underestimated the true oxygen demands when compared with predictions from tests conducted at higher elevations. He postulated that the reasons for this may be associated with differences in the contribution from stored elastic energy and differences in the ratio of eccentric and concentric work during tests predicting oxygen demand at 1% compared with test predictions from higher elevations.

Summary

To summarise the impact of determining the anaerobic capacity from accumulated oxygen deficit several issues need to be addressed: The first is that the method relies strongly on the practice of extrapolating an oxygen demand for supramaximal conditions from a power-O_2 linear relationship established under submaximal conditions. Despite a strong defence of constant and similar "in situ" conditions during supramaximal exercise by Medbφ et al. (1988) and Medbφ (1991) concern for the validity of extrapolation still exists. Assumptions of a constant ATP turnover rate are yet to be supported for supramaximal exercise conditions. The work of respiratory physiologists appears to indicate non-linear oxygen uptake costs and kinetics under supramaximal conditions, which are not predictable from submaximal exercise. The non-metabolic additional oxygen uptake demands of cardiorespiratory and stabilising muscles under supramaximal conditions must also be considered. Nevertheless, Medbφ et al. (1988) were able to quantify measured accumulated oxygen deficits with the results from a combination of invasive studies. The accumulated oxygen deficit method for determining anaerobic capacity appears to be sensitive enough to detect differences in the status of training between and within subjects and changes in the amount of muscle mass participating in the test.

Because it does not necessarily require invasive procedures and is of a short powerful nature, the accumulated oxygen deficit method may well be suitable for use in pediatric populations. The method by which oxygen deficit was reported in children previously (Eriksson et al., 1973) was obtained from an estimate of a single data point (peak oxygen uptake). This method has since been criticised. To date, no studies have reported investigations of pediatric populations where anaerobic capacity has been estimated from the accumulated oxygen deficit method.

Chapter Three

Methods

Chapter Three

Methods

This chapter describes the subjects, and the general data collection procedures common to two or more of the four studies comprising the research. The statistical procedures which are common to two or more of the related studies are also outlined.

Subjects

Altogether, 132 subjects, 87 males and 45 females have participated in one or more of the studies in this thesis. The subjects ranged in age between 6 and 12 years.

Table 3.1: The range of descriptive characteristics of subjects in the four studies

Study	n	Age (yr)	Mass (kg)	Height (cm)	BSA (m^2)	VO_2max ($ml \cdot kg^{-1} min^{-1}$)
One	75	6-12	23-42	121-150	.87-1.3	-
Two	32	6-12	23-42	122-152	.99-1.4	-
Three	18	10-11	32-53	142-160	1.2-1.4	36-62
Four	13	10-11	33-42	142-155	1.2-1.3	36-58

Each subject was informed both verbally and in writing of the protocol, risks, and purpose of each study. Subjects were instructed that as volunteers in a study, their continuation was not compulsory. The children were required to provide written consent from their parent/s or guardian and themselves before participating in experiments. Prior to the conduct of the research, approval was obtained from the Ethics Committee of the University.

General Data Collection and Procedures

(a) Ergometers

For Studies One and Two a Monark™ cycle ergometer was adapted for use by children. The seat pillar height was lowered to allow relatively small children to participate in the testing. The standard crankarm length of 17.5 cm was used in all testing. Precision of the resistance was ensured by an electronic force transducer (Extran 0-10 kg) attached to the friction belt of the ergometer. Pedal revolution rate and flywheel travel were obtained via a light sensor with a 12-point photointerrupter disk fitted to the flywheel. An IBM computer was programmed to collate and calculate data from the exercise bouts. Output was computed at 10 hertz. This resolution is a much higher than previously reported (Bar-Or, 1987) and was selected to promote a more precise measure of instantaneous power output.

A CYBEX™ (Met 100, Lumex) electronically-braked cycle ergometer which could be adapted for constant power or isokinetic resistances was used by the children in Studies Three and Four. Throughout the tests on this ergometer, screen displays of time, power, and pedal frequency were provided. This cycle ergometer was used in the constant power mode in Study Three and in the isokinetic mode in Study Four, respectively. Toe stirrups were used on both cycle ergometers in the testing. The children were required to remain seated throughout these tests.

(b) Determination of metabolic data

Determination of metabolic data (peak oxygen uptake, RER, and steady state VO_2) was obtained by open circuit analysis of expired air. Expired air volume was measured as the subject breathed through a Hans Rudolph two-way valve which was connected to a Pneumoscan ventilometer with a Mark 2 turbine flow transducer. Gases were analysed for the fractions of O_2 and CO_2 by Applied Electrochemistry analysers S-3A (O_2) and CD-3A (CO_2). The analysers were calibrated before and after each test, using calibrated gases of a known quantity (CIG, Melbourne). An IBM-PC provided direct calculations and on-line printouts at 15 s intervals.

(c) Familiarization to the laboratory

Prior to each of the studies, the children were familiarized with working of the cycle ergometer. In Studies Three and Four, the children were also given the opportunity to experience wearing the apparatus for monitoring expired air and heart rates. During the orientation to laboratory procedures session, subjects were introduced to the fundamental skills of acceleration and deceleration of the Monark™ cycle ergometer (Studies One and Two), maintaining 90 rpm for all accumulated oxygen deficit pretests (Studies Three and Four), and exertion at supramaximal intensities (Studies Three and Four). During the familiarization visit the most appropriate seat height for each child was recorded for all subsequent testing.

(d) Warm up protocol

Prior to all supramaximal intensity tests a warm up was conducted. In Studies One and Two the warm up consisted of cycling for three min (children less than 33 kg) or five min (children more than 33 kg). The children were required to maintain 40-50 rpm against 0.5 kp (children less than 33 kg) or .750 kp (children more than 33 kg) on the modified cycle ergometer. In Studies Three and Four the warm up was similar for all children because the body mass of the group was more homogeneous than in Studies One and Two. In the two later studies, the warm up consisted of a five minute duration with a resistance of 50 w at 90 rpm, followed by a 5 min rest interval immediately prior to testing.

(e) Peak oxygen uptake protocol

In Studies Three and Four, peak the oxygen uptake of the children was assessed using an incremental exercise protocol to volitional exhaustion. The testing protocol dictated that twenty-five watt increments were imposed on the cycle ergometer every minute until volitional exhaustion and, or, several of the criteria for peak oxygen uptake were observed. These criteria included attainment of heart rate values which approximated 95 % of predicted maximal heart rate, a respiratory exchange ratio (RER) greater than 1.0, a plateau of oxygen consumption at high intensities of approximately less than 2.0 $ml \cdot kg^{-1} min^{-1}$ or an observation of apparent exhaustion (Zwiren, 1989). The criteria of a plateau of a steady oxygen uptake with increasing workload needs to be examined with caution in that the majority of child-based populations may not display a plateau of this nature (Rowland, 1992). During the peak oxygen uptake tests the children were required to maintain a pedal frequency of 90 rpm.

(f) Steady state submaximal testing

In the accumulated oxygen deficits experiments (Studies Three and Four) a series of steady state submaximal tests were also conducted. Steady state was defined as mean VO_2 values for consecutive minutes not varying by more than ± 3 $ml.kg.^{-1} min^{-1}$. There were 4-5 steady state tests performed by each child. The number of tests depended on the highest workload at which the child could maintain steady state. Resistances began at 50 w and continued to as high as 150 w for one subject in Study Three. These tests represented a range of between 40 and 72% of peak oxygen uptake of the subjects. The children with the smaller maximal workload were often unable to provide more than four, discrete steady state performances because of the limited workload range in which steady state could be achieved. In order to compare the children's data with those of adults, the adult-based protocol for accumulated oxygen deficit was adapted. Thus, in this protocol the pedal frequency was required to be maintained at 90 rpm. Steady state oxygen uptake was obtained from a non-linear exponential equation (KaleidaGraph, 1989). Data from the 4-5 steady state tests enabled the power-O_2 relationship to be established. This was calculated by a standard, least squares linear regression equation. From this information a supramaximal workload was obtained with an inversion of the equation $y = a + b(x)$, to $x = (y-a)/b$; where $y = VO_2$, and x = work load/intensity. In an explanation of the accumulated oxygen deficit method Medbo (1991) stated that subjects had performed between ten, to more than forty steady state tests. He also indicated that before calculating the least squares linear regression equation, measurements of individuals' steady state responses with residuals more than three times the scatter of the regression line were excluded from the equation. On these two points the protocol used in Studies Three and Four differ from Medbφ et al. (1988) and Medbφ (1991). The children in these studies did not provide a large enough range of steady state responses to permit outlying residual data to be excluded.

(g) Analysis of expired air under supramaximal exercise conditions

Steady state and peak oxygen uptake analysis have been described in a previous section within this chapter. In supramaximal intensity tests Douglas Bags were used to collect expired air. Fractions of O_2 and CO_2 were measured on the Applied Electrochemistry Analysers at a sampling rate of 330 $ml.s^{-1}$ for both O_2 and CO_2. The volume of expired air was measured with a Parkinson-Cowan ventilometer. The ventilometer was previously calibrated against a Tissot spirometer.

Experiment Protocols

A summary of the protocols of the four studies has been presented in Table 3.2. All supramaximal intensity tests were conducted on separate days. Throughout these tests positive but quite, verbal encouragement was provided in as 'standardized' form as was possible. The exercise duration of tests in Studies One and Two was 30 s. The test duration was measured and displayed by computer software. The children were encouraged to perform an all-out effort for 30 s during these WAnTs. The children began unloaded cycling approximately 15 s before the commencement of the WAnT. This enabled them to help overcome the inertial forces at the onset of the resistance which coincided with the start of the WAnT. In Study One the resistance varied randomly between 0.04-0.08 kp.kg.BM and in Study Two the resistance used was 0.075 kp.kg.BM. This force represented mechanical work of 4.41J per pedal revolution per kg of body mass.

In Studies Three and Four, test duration was to exhaustion and was an inverse reflection of intensity. The longest tests were those conducted at 110% and the shortest tests were those conducted at 150%. In these tests, no unloaded cycling was permitted before the onset of the supramaximal resistance on the CYBEX™ (Met 100). In Study Three the test was terminated when the pedal frequency decreased below 60-70 rpm over any 2-3 s period. In Study Four the test exhaustion was denoted by a 2-3 second display of a power which was individually calculated to represent 95% of peak oxygen uptake. The research in Study Three was conducted in a constant power mode and children were required to maintain a pedal frequency of 90 rpm. The research in Study Four was conducted in an isokinetic mode with a fixed pedal frequency at 90 rpm.

Table 3.2: A summary of the protocol used in each of the four studies.

Study	Summary of protocol
One	Children rode all-out for 30 s in WAnTs, four times against four different resistances.
Two	Children rode all-out for 30 s in WAnTs, with four repeats of the one resistance. Tests were also randomly conducted with and without the presence of a feedback computerized game linked to pedal frequency.
Three	Children cycled to exhaustion against individually predicted constant loads representing 110, 130, and 150 relative percent of peak oxygen uptake. The children were required to maintain a pedal frequency of 90 rpm.
Four	Children cycled to exhaustion against an isokinetic braking force fixed at 90 rpm.

Overview of the Statistical Presentation of the Data

All data are reported in means and standard errors of the mean (M±SEM). Performance data were generally analysed using a univariate approach with repeated measures design. Univariate ANOVAs which were conducted are outlined in Table 3.3 (BMDP, 1985). Newman-Keuls post hoc analysis tests were used where appropriate (Kirk, 1962). Intraclass correlation coefficients (R) were used in Studies Three and Four to assess test reliability. Independent t-tests were conducted to determine if means of the descriptive characteristics of males and females were significantly different in Studies One, Three and Four (Minitab, 1988). The .05 level of significance was applied for all general statistical analysis.

Table 3.3: Summary of the statistical designs (repeated measures ANOVA) used in the four studies

Study	Outline of ANOVA	Nature of the ANOVA
One	4 x 2 x 4	resistance by sex by age
Two - Part (a)	4 x 4	age by trial
Part (b)	4 x 4 x 2	age by trial by feedback
Three	2 x 3	sex by supramaximal intensity
Four	2 x 2	sex by trial

Chapter Four

Study One

Performance Characteristics of Children Using Various Load Applications on the Wingate Anaerobic Test.

Performance Characteristics of Children Using Various Load Applications on the Wingate Anaerobic Test.

Abstract

This study examined the responses of children exercising against varying load applications in short-term, all-out cycling tests. The load applications were 0.04, 0.065, 0.075, and 0.08 kiloponds for every kilogram of body mass (kp·kg.BM). Results for the peak and mean power performances in 30 s Wingate Anaerobic Tests (WAnT) were recorded for a wide age range of children (6, 8, 10, and 12 years of age). Univariate ANOVAs with repeated measures on resistance, and Newman Keuls post hoc analysis tests revealed that the absolute peak and mean power responses of the children increased incrementally with age. In all of the age groups the three higher resistances (0.065, 0.075, and 0.08 kp·kg.BM) produced significantly higher peak and mean power performances than did the 0.04 kp·kg.BM resistance. The results confirmed a number of previous studies in which varying resistances have been used with specific ages of children. Among the three higher resistances there was no one resistance which elicited a significantly more powerful performance within the sample of children in the present study.

Performance Characteristics of Children Using Various Load Applications on the Wingate Anaerobic Test.

Introduction

In a review of the anaerobic characteristics of children, Zwiren (1989) emphasized the importance of choosing the appropriate load application for peak performances in the Wingate Anaerobic Test (WAnT). Yet within the available literature, fragmented data exist on responses to varying load applications on the WAnT. This applies particularly to studies crossing the broad age spectrum of children performing the test on Monark cycle ergometers. Dotan and Bar-Or (1983) recommended resistances of 0.0667 and 0.0703 kiloponds for every kg of body mass (kp·kg.BM) in 13-14-year-old females and males, respectively. The original WAnT prescribed a resistance of 0.075 kp·kg.BM (Alayon et al., 1974), however, the subjects used in this study were nonathletic young adults. Two publications in particular contain summary tables of performances on the WAnT demonstrating a diverse range of studies using varying resistances and ergometer devices (Bar-Or, 1987; Dotan and Bar-Or, 1983). Van Praagh et al., (1989; 1990) recommended using load applications of 0.064 kp·kg.BM with 7-year-old males and 0.085 and 0.068 kp·kg.BM with 11-year-old males and females, respectively. These applications were recommended following investigations into individual force and velocity curves from performances of children on isokinetic cycle ergometers. Vandewalle et al. (1987) hypothesized that the original recommendation of 0.075 kp·kg.BM may be most applicable for child-based populations but suggested that more research was necessary in this area. A dearth of information profiling WAnT performances through the broad spectrum of childhood can been identified from the literature available. It is also apparent that data are needed for performance profiles of children using the more commonly available Monark cycle ergometer.

Purpose

The purpose of this study was to examine WAnT performances of male and female children aged 6, 8, 10, and 12 years using varying load applications on a Monark cycle ergometer. The varying loads applications were 0.04, 0.065, 0.075, and 0.080 kp·kg.BM and were selected from the somewhat limited recommendations of resistance protocols previously outlined for children.

Methods

Seventy-five healthy normal children volunteered as subjects for the study. At the time of the study none of the children was participating in organized sporting programs beyond the school curriculum demands. Following a familiarization session, four WAnTs were performed in random order on separate days utilizing the resistances of 0.04, 0.065, 0.075, and 0.08 kp·kg.BM. In each of these tests the children were asked to perform an all-out effort for 30s. Specific details of the WAnT have been previously described (Ayalon et al., 1974; Bar-Or, 1987).

The Monark cycle ergometer used in this experiement has been described previously (Chapter Three). For the purpose of this study the dependent variables that were examined were peak and mean power outputs from WAnTs. Peak power was defined as the highest mechanical power output in watts elicited over the 30 s test and was also expressed in relative terms as watts per kg of body mass ($w.kg^{-1}$). Mean power was defined as the averaged mechanical output produced over the 30 s of the test and was also expressed in watts and watts per kilogram of body mass ($w.kg^{-1}$).

The data were treated with two main statistical analyses. Independent t-tests examined the descriptive characteristics of males and females in the study. For each of the performance responses, a univariate ANOVA was completed involving age group, by sex, by resistance with repeated measures on resistance. Tests for power of the analysis of variance of the F test were conducted to determine the probability of falsely rejecting the null hypothesis for each of the measured variables. Noncentral F tests were conducted to determine equality among the resistances. (Londeree et al., 1990). Restrictive assumptions about variance and covariances of the repeated measured analyses were acknowledged and significant probabilities reflect the adjusted degrees of freedom, where appropriate. Newman Keuls post hoc analysis tests were applied to simple effects wherever interactions were significant (Keppel, 1982). The .05 level of significance was applied for all general statistical analyses. Data are reported in M±SEM.

Results

Descriptive data for the subjects are presented in Table 4.1. No significant differences in height, weight, and body surface area were observed between the sexes in any of the age groups. Table 4.2 presents data for the four recorded variables from male and female children in each age group. (See also Appendix 1a-d)

Results from tests for power of the analyses of variance produced F values of 3.56, 5.51, 5.68, and 5.71 for peak power, mean power, relative peak power, and relative mean power, respectively. For each of the measured variables, the probability of rejecting a false null hypothesis was greater than .99 ($\mu_1 = 2$, $\mu_2 = 72$) (Kirk, 1962). Results of the noncentral F tests indicated that the calculated F values (7.33, 17.75, 17.34, and 17.30, for peak and mean power, and relative peak and mean power, respectively) exceeded the critical F values, for a noncentral F test.

Table 4.1: Descriptive characteristics of male and female children subjects (n=75)

Age (yr)	n	Sex	Mass (kg)	Height (cm)	B.S.A (m^2)
12	9	m	42.5	149.6	1.33
			(3.1)	(3.2)	(0.1)
	5	f	45.0	152.9	1.38
			(3.6)	(2.5)	(0.1)
10	9	m	37.2	149.7	1.26
			(2.2)	(6.4)	(0.1)
	10	f	36.5	144.2	1.21
			(1.4)	(5.3)	(0.0)
8	10	m	31.3	136.5	1.11
			(1.4)	(2.2)	(0.0)
	9	f	28.4	131.9	1.04
			(1.5)	(3.2)	(0.0)
6	17	m	24.5	123.3	0.915
			(0.9)	(1.0)	(0.0)
	6	f	22.9	120.9	0.875
			(1.1)	(1.9)	(0.0)

M±SEM

Table 4.2: Results from WAnTs from children against four resistances for (a) peak power [watts], (b) mean power [watts], (c) relative peak power [$w.kg^{-1}$], and (d) relative mean power [$w.kg^{-1}$].(M±SEM)

(a) Peak Power [watts]

Age	6 years		8 years		10 years		12 years	
Resistance	females	males	females	males	females	males	females	males
.04	81(3)	113 (6)	131 (10)	167 (12)	188 (9)	189 (12)	244 (13)	228 (17)
.065	122(7)	154 (7)	185 (14)	222 (15)	267 (14)	286 (18)	407 (33)	317 (20)
.075	149 (8)	176 (9)	196 (13)	250 (12)	265 (10)	262 (16)	350 (30)	361 (25)
.08	138 (16)	171 (8)	211 (14)	240 (18)	297 (18)	291 (18)	383 (30)	353 (22)

(b) Mean Power [watts]

Age	6 years		8 years		10 years		12 years	
Resistance	females	males	females	males	females	males	females	males
.04	62 (4)	86 (5)	102 (8)	130 (8)	156 (8)	158 (9)	204 (11)	189 (15)
.065	91 (8)	119 (5)	155 (11)	187 (11)	215 (11)	209 (17)	305 (23)	259 (16)
.075	111 (8)	128 (7)	166 (12)	190 (11)	218 (6)	199 (12)	284 (24)	289 (20)
.08	106 (11)	132 (6)	171 (12)	183 (12)	236 (13)	226 (16)	319 (25)	290 (21)

(c) Relative Peak Power [$w.kg^{-1}$]

Age	6 years		8 years		10 years		12 years	
Resistance	females	males	females	males	females	males	females	males
.04	3.6 (0.1)	4.6 (0.2)	4.5 (0.1)	5.2 (0.2)	5.1 (0.1)	5.1 (0.1)	5.5 (0.4)	5.4 (0.2)
.065	5.2 (0.1)	6.0 (0.2)	6.5 (0.2)	7.0 (0.4)	7.2 (0.4)	7.6 (0.2)	9.1 (0.6)	7.9 (0.3)
.075	6.5 (0.3)	7.2 (0.2)	7.0 (0.2)	7.9 (0.4)	7.3 (0.3)	7.1 (0.2)	7.9 (0.5)	8.6 (0.3)
.08	6.0 (0.6)	6.7 (0.2)	7.2 (0.2)	7.5 (0.4)	7.8 (0.3)	7.8 (0.3)	8.6 (0.6)	8.4 (0.2)

(d) Relative Mean Power [$w.kg^{-1}$]

Age	6 years		8 years		10 years		12 years	
Resistance	females	males	females	males	females	males	females	males
.04	2.7 (0.0)	3.5 (0.1)	3.5 (0.1)	4.1 (0.2)	4.2 (0.1)	4.2 (0.1)	4.6 (0.2)	4.4 (0.1)
.065	3.9 (0.2)	4.7 (0.2)	5.3 (0.1)	5.7 (0.2)	5.8 (0.2)	5.7 (0.4)	7.0 (0.5)	6.2 (0.2)
.075	4.9 (0.3)	5.3 (0.2)	5.7 (0.1)	6.2 (0.3)	6.1 (0.2)	5.4 (0.3)	6.4 (0.4)	6.8 (0.2)
.08	4.6 (0.4)	5.3 (0.2)	5.8 (0.1)	6.1 (0.3)	6.4 (0.3)	6.1 (0.3)	7.4 (0.4)	6.9 (0.2)

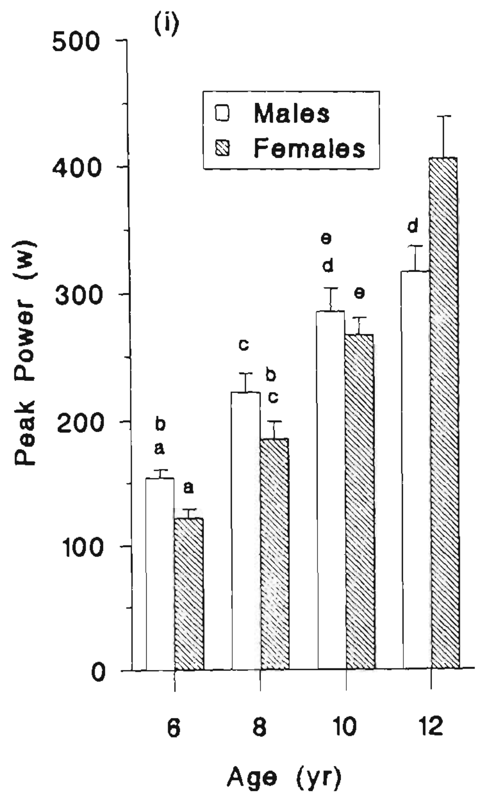
A significant interaction for resistance by sex by age (R x S x A) occurred in the responses for peak and mean power outputs $\underline{F}(9,201) = 4.42$ $\underline{p} \leq 0.0001$ and $\underline{F}(9,201) = 2.28$, $\underline{p} \leq 0.02$. Analyses of simple effects at each resistance indicated a significant S x A effect only at the 0.065 kp·kg.BM resistance for PP $F(3, 67) = 6.17$, $p \leq 0.002$ and MP $F(3, 67) = 3.59$, $p \leq 0.02$. Post hoc analyses demonstrated that age and sex differences within the 0.065 kp·kg.BM resistance were associated with different trends among the scores for the younger and older males and females. At this resistance the 6-year-old females were 33, and 28 watts less than the males in peak and mean power results, respectively, while the 12-year-old females were 80 and 40 watts greater than the 12-year-old males in peak power and mean power, respectively [Figure 4a (i) and (ii)].

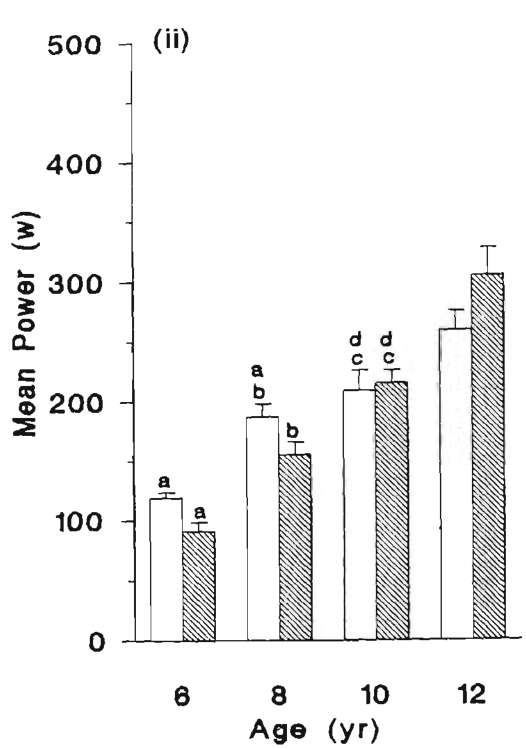
A significant two-way interaction also occurred between resistance and age for peak and mean power $F(9, 201) = 10.42$, $p \leq 0.0001$, and $F(9, 201) = 7.91$, $p \leq 0.0001$, respectively. Simple main effects confirmed a significant age effect at each of the four resistances. Post hoc analyses indicated that within each resistance, the peak and mean power of each age group was significantly different from the other groups. The differences demonstrated an incremental age-related response to power output in children. Univariate analyses with repeated measures for resistance within each of the four age groups demonstrated that peak and mean power elicited from the three higher resistances were significantly greater than power outputs at 0.04 kp·kg.BM [Figure 4b (i) and (ii)].

A significant two-way interaction for resistance and sex was present only in absolute peak power values $F(3, 201) = 3.59$, $p \leq 0.01$. Simple main effects analysis revealed that this had occurred only at the 0.075 kp·kg.BM resistance where the males and females had elicited peak power outputs of 247 ($\pm$12) and 235 ($\pm$14), respectively.

No significant differences were reported for the main effect of sex $F(1, 67) = 1.11$, $p \leq 0.29$ and $F(1, 67) = 0.34$, $p \leq 0.56$ for peak and mean power, respectively. Peak and mean power results demonstrated a significant main effect for age, $F(3, 67) = 63.05$, $p \leq 0.0001$ and $F(3, 67) = 68.15$, $p \leq 0.0001$, respectively. The significant age effect can be observed in Figure 4b.

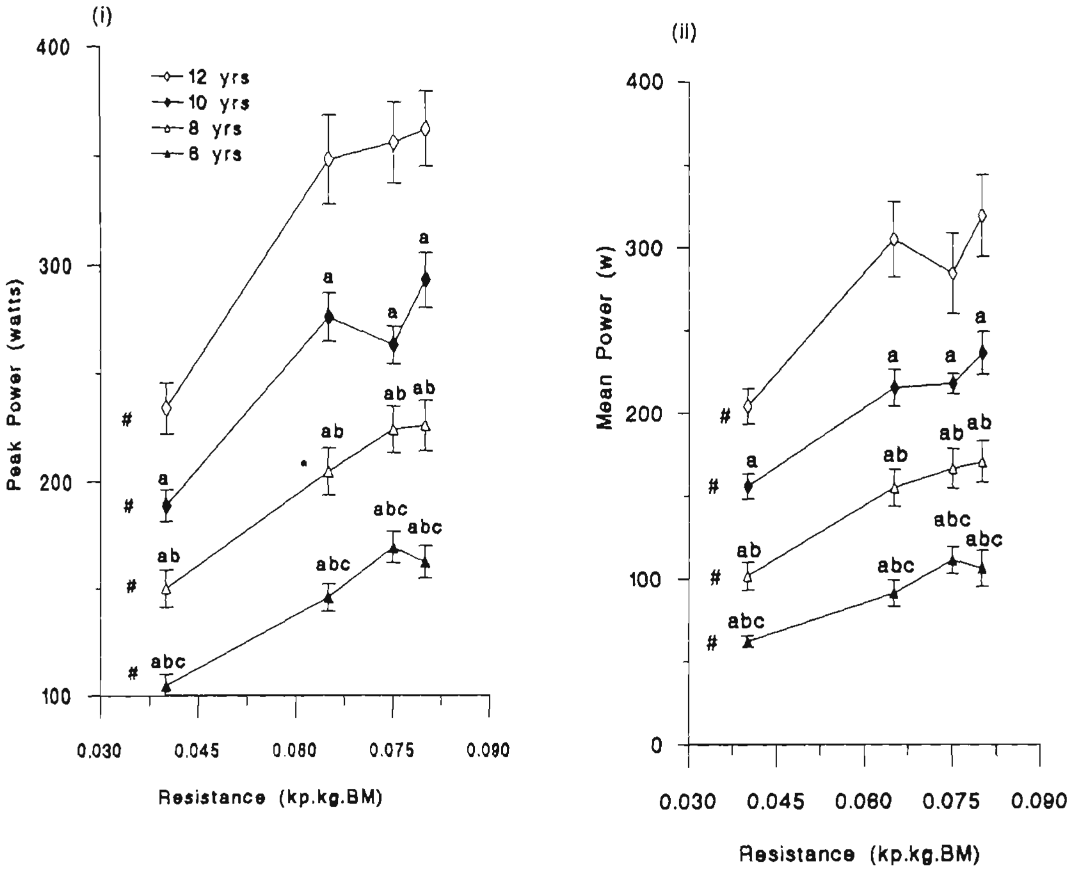
Figure 4a: (i) Peak power (w) and (ii) Mean power (w) of male and female children during 30 s of maximal cycling exercise against resistances of 0.065 kp·kg.BM.





Like symbols denote **no** significant difference ($\underline{p} \geq .05$)

Figure 4b: (i) Peak power (w) and (ii) mean power (w) output during 30 s of maximal cycling exercise at four different resistance in children aged 6, 8, 10, and 12 years.



a denotes significantly < 12 years

b denotes significantly < 10 years

c denotes significantly < 8 years

# denotes significantly < 0.08, 0.075, and 0.065kp·kg.BM

* denotes significantly < 0.075 kp·kg.BM only

Results in relative peak power ($w.kg^{-1}$) revealed a R x S x A interaction $F(9, 201) = 2.09$, $p \leq 0.03$. Simple effects analyses at each of the resistances indicated a significant S x A interaction at the 0.04 and 0.065 kp·kg.BM resistances ($p \leq 0.01$ and 0.02, respectively). Post hoc analysis tests indicated consistent superiority in the relative peak power outputs of the 12-year-old females compared with males in the same age and males and females of other age groups at each of these resistances. No significant R x S x A interaction was reported for relative mean power outputs $F(9, 201) = 1.73$ $p \leq 0.083$.

In relative peak and mean power outputs, significant R x A interactions were observed $F(9, 201) = 5.10$, $p \leq 0.0001$ and $F(9, 201) = 3.09$, $p \leq 0.002$, respectively. Simple main effects demonstrated significant age effects at each of the four resistances. In general the post hoc analysis tests reported consistent differences between 12 and 6-year-old children but were not as strong (Table 4.3 a and b).

No significant differences were reported for the main effect of sex $F(1, 67) = 3.45$, $p \leq 0.07$ and $F(1, 67) = 1.09$, $p \leq 0.30$ for relative peak, and mean power, respectively. Relative peak and mean power results demonstrated a significant main effect for age, $F(3, 67) = 3.67$, $p \leq 0.0001$ and $F(3, 67) = 23.7$, $p \leq 0.0001$, respectively.

Table 4.3a: Summary of relative peak power output (w.kg^{-1}) differences in the children (data of males and females when combined) by age groups.

Age	n		Resistance	(kp·kg.BM)	
(yr)		0.04	0.065	0.075	0.08
12	14	5.4	8.5[a]	8.2[a]	8.5[a]
		(0.2)	(0.3)	(0.3)	(0.2)
10[b]	19	5.12	7.4[a]	7.2[a]	7.8[a]
		(0.1)	(0.3)	(0.2)	(0.2)
8[b]	19	4.8	6.7[a]	7.4[a]	7.3[a]
		(0.1)	(0.2)	(0.2)	(0.2)
6	23	4.1	5.6[a]	6.8[a]	6.3[a]
		0(.1)	(0.2)	(0.2)	(0.2)

[a] denotes **no** significant difference between resistances

[b] denotes **no** significant differences between age groups ($p \geq 0.05$)

Table 4.3b: Summary of relative mean power output (w.kg^{-1}) differences in children by age groups

Age	n		Resistance (kp·kg.BM)		
(yr)		0.04	0.065	0.075	0.080
12	14	4.5	6.6[a]	6.6[a]	7.0[a]
		(0.1)	(0.2)	(0.2)	(0.2)
10[b]	19	4.2	5.7[ab]	5.7[a]	6.3[a]
		(0.1)	(0.2)	(0.2)	(0.2)
8[b]	19	3.8	5.5[ab]	6.0[a]	6.0[a]
		(0.1)	(0.1)	(0.2)	(0.2)
6	23	3.1	4.3	5.1[a]	5.0[a]
		(0.1)	(0.2)	(0.2)	(0.2)

[a] denotes **no** significant difference between resistances

[b] denotes **no** significant differences between age groups ($p \geq 0.05$)

Discussion

Seventy-five healthy, active children took part in a series of WAnTs to examine the effect of varying resistances on peak and mean power performances. The four resistances were 0.04, 0.065, 0.075, and 0.08 kp·kg.BM and were performed in randomized order by children aged 6, 8, 10, and 12 years of age.

Throughout the study very few sex differences occurred. There was no main effect for sex. From simple effects analyses the only interaction involving sex and age was registered at the 0.065 kp·kg.BM resistance for both the absolute peak and mean powers. Post hoc analyses demonstrated a marked superiority of the females over males at 12 years of age, while this difference was reversed for children of 6 and 8 years of age (Figure 4a). Even though pubertal stage was not directly assessed it could be suggested that the more advanced maturational status commonly observed in 12-year-old females when compared with 12-year-old males may well be reflected in the results of this study (Tanner, 1962). An explanation for age and sex only interacting at the 0.065 kp·kg.BM resistance is difficult to find and may well be an artifact. This artifact may be associated with the sample size being nonrepresentative of this age group. In general both sexes provided an incremental effect in the results of the absolute peak and mean power responses. When the scores were expressed in relative terms the pattern for incremental responses in relative peak and mean power with age was not quite as evident, particularly for the 8-10-year-old groups. Perhaps the one consistent result from relative measures was that the 10-12-year-old children obtained values which were generally greater than those of the 6 -year-old children.

Table 4.4 presents a comparison of the data obtained in this study with those in previously published literature. Children in the present study compare favorably in absolute scores to children tested elsewhere however, in relative terms the older children's data in the present study were somewhat lower in comparison with those appearing in international literature. It appears that the body mass of the 10-year-old children in the present study was somewhat higher than the children reported by Rostein et al. (1986). A relative peak power score of 8.8 $w \cdot kg^{-1}$ was obtained by the 10-11-year-old children trained by Rostein et al. (1986). These children had a mean body mass of 33 kg, whereas the 10-year-old group in the present study had a mean body mass of approximately 37 kg and scored only 7.4 $w \cdot kg^{-1}$. Associating the lower relative peak power performance of children in the present study with higher body mass was not possible with the 12-year-old males. The 12-year-old males in the present study averaged 8.4 $w \cdot kg^{-1}$ for their relative peak power performance and weighed 42.5 kg. The 12-year-old male sprinters tested by Thorland et. al. (1990) produced a relative peak power of 9.0 $w \cdot kg.^{-1}$ yet still weighed 42.4 kg. The 12-year-old distance runners tested by Thorland et al. (1990) obtained a relative peak power average of 8.6 $w \cdot kg.^{-1}$ and weighed only 36.49 kg. Therefore the older children who participated in the present study appeared to have lower relative peak power performances when compared with children of the same age perhaps because they were heavier and, or less conditioned.

Table 4.4: Comparison of mean results of Wingate anaerobic performance tests with previously reported data on children

Authors	Group (yr)	Resistance (kp.kg.BM)	Peak power (w)	Peak power ($w.kg^{-1}$)
Present study	males 6	0.065	154	6.0
Van Praagh et al., 1989	males 7	0.064*	146	5.8
Present study	females 8	0.065	222	6.5
	males 8	0.065	222	7.6
Present study	males 10	0.065	286	7.4
Rostein et al., 1986	males 10	0.067	289 (experimental)	8.8
			267 (control)	8.0
Present study	females 12	0.065	407	9.1
	males 12	0.080	361	8.4
Van Praagh et al., 1990	females 11	0.068*	310	7.4
	males 11	0.085*	415	9.7
Present study	males 12	0.075	361	8.6
Thorland et al., 1990	males 12	0.075	384.8 (sprinters)	9.0
			314.0 (distance)	8.6

* force-velocity protocol

The incremental age effect on the absolute peak and mean power outputs by children was well supported in the literature (Bar-Or, 1983, 1987). Even the relative scores of peak and mean power of the 12-year-old children were consistently and significantly higher than the three younger groups. An age-related response was evident in the relative scores of the 6-year-old children which were consistently and significantly lower than the older three groups of children. Bar-Or (1983) also reported an age-related response when he stated that even in relative terms (i.e., $w{\cdot}kg^{-1}$), younger children's anaerobic performances in peak and mean power were inferior to older children.

Inbar and Bar-Or (1986) discussed the underlying mechanisms which may have contributed to the poorer absolute and relative performances in peak and mean power in children when compared with adults. They postulated that the poorer performance of children was associated with the biochemical characteristics of the muscle or the process of activation of the muscle's motor units. Inbar and Bar-Or (1986) believed that the lower anaerobic performance of children was attributable to research findings indicating a lower concentration and utilization rate of glycogen in the muscle (Eriksson, 1980; Eriksson et al., 1971; Eriksson and Saltin, 1974). Inbar and Bar-Or (1986) also referred to previous findings of children's lower levels of the enzyme limiting the rate of glycolytic activity, phosphofructokinase (Eriksson et al., 1973), as being an important consideration for poorer anaerobic performance. Berg and Keul (1988) compared the muscle enzyme activities of males and females of varying ages and reported age-related increases in several of the key glycolytic enzymes. The finding of lower acidosis levels in children by Kindermann et. al. (1975) also supported the suggestions of Inbar and Bar-Or (1986). Macek (1986) associated the lower blood lactate levels of children with reduced sympathetic nervous system activity causing comparatively less vasoconstriction in blood vessels and faster clearing of the lactate from the working muscles to the liver for gluconeogenic processes in the Cori cycle. The hypothesis by Macek (1986) was that children may possess the ability to clear the lactate that they produce more efficiently than adults. Macek (1986) also considered that children's shorter half-time to oxygen increase at the onset of exercise contributed to reduced levels of lactic acid production in children when compared with adults. Cumming et. al. (1980) questioned previous findings of lower levels of blood lactate in children compared with adults by reporting blood lactate levels of 9.5 $mm.l^{-1}$ to 12.1 $mm.l^{-1}$ in children aged four to five years. Cumming et al. (1980) reported these findings after children ran for two minutes at maximal effort. They further postulated that their findings were higher than previously reported for children because they had worked their subjects at greater anaerobic intensities than previously reported in lactate studies on children. Zwiren (1989) also made reference to the apparent higher ventilatory threshold of children compared with adults as an indicator of reduced anaerobic performance of children. Sargeant and Dolan (1986) believed that the differences in the peak and mean power outputs of children should really be considered in relation to the mass of the pennate and oblique orientation of the muscle fibers, which they believed could continue to contribute to power development even after longitudinal growth has ceased. The issue of biochemical and physiological mechanisms involved in reduced anaerobic performance by children remains largely speculative due to many ethical and moral constraints associated with the pediatric research area, particularly when normal healthy children are being tested in non clinical settings.

The findings of the present study support many of the previous load applications used in work with pediatric populations. Results of the present study somewhat endorse the suggestion of Vandewalle et al. (1987) that the 0.075 kp·kg.BM may be the best resistance for children performing the WAnT. The results also compared favorably with the finding of Van Praagh et al. (1990) that 0.064 kp·kg.BM could be used to gain powerful performances with 7-year-old children. The finding of Van Praagh et al.

(1990) that 0.085 kp·kg.BM elicited optimal performances in 11-year-old males was not tested by the present study because it was estimated to be too difficult a workload for the 6-year-old children to sustain for the 30 s of the WAnT. The 0.04 kp·kg.BM which was deliberately included for the younger and smaller children proved to be much too light for any large force to be elicited. Overall, the results suggest that more powerful performances on WAnTs by children may be elicited from the broad range of load applications between 0.065 and 0.08 kp·kg.BM, rather than lighter resistances.

The lack of significant main effects differences for sex and the relatively small number of interactive effects between sex and age reported in the present study have been supported in previous literature. Bar-Or (1983) stated that prior to the age of puberty, the physiological characteristics of males and females are largely equal. Van Praagh et al. (1990), however, found significant differences in the performances of 11-year-old males and females in absolute peak and mean power on the WAnT test only when scores were corrected for lean thigh volume. When this correction was made, the males' scores were significantly greater than the females' scores. Since lean thigh volume was not measured in the present study this finding was difficult to evaluate. In the present study when scores were corrected for body mass, significant differences remained between the older and younger children.

Results from the present study may suggest that the WAnT is insensitive to small incremental alterations in resistance settings. Perhaps more significant findings could be found from larger increments within this range of resistances. The results of the present study reject the use of a 0.04 kp·kg.BM for use on the WAnT with children. The study also indicated an incremental age-related response in peak and mean power in absolute terms and continued to demonstrate superior scores of the older children compared with younger children even when scores were expressed in relation to body weight. Within the 8-10-year-old groups of children the age-related incremental power output differences were not as evident when data was expressed in relative terms.

Chapter Five

Study Two

Determining the Variability of Performance on Wingate Anaerobic Tests in Children Aged 6-12 Years

Determining the Variability of Performance on Wingate Anaerobic Tests in Children Aged 6-12 Years

Abstract

In two parts, this study investigated variability of performance in Wingate anaerobic tests (WAnTs) of normal, healthy, male children aged 6, 8, 10, and 12 years. The purpose of the first part of the study was to investigate the mean coefficient of variation (C.V.=(S.D./X)*100) of children who performed four WAnTs over a period of four weeks. The results revealed age-related differences in the performance data of peak power (PP), and mean power (MP) but no differences between age groups in fatigue index (FI%)=[(PP-P_{end})/PP*100]. C.V. data from this group of children did not differ significantly between ages in any of the dependent variables. Coggan and Costill (1984) measured the variability of male adults during 30 seconds of highly intense cycling and reported C.V. values in PP and MP performances of 6.7 and 5.4%, respectively. C.V.values in children the first part of the present study were 7.3 and 6.7% for PP and MP, respectively. The C.V. in the FI% of the children (26.7%) however differed substantially from the previously studied adults (10.3%). The second part of the study was conducted in an attempt to decrease the C.V. in the FI% performances of children in the WAnT. The purpose of this part of the study was to examine the extent to which a computerized on-screen game, which was linked to pedal cadence affected the variability of children performing WAnTs. A significant decrease was obtained in the C.V. of the FI% in the presence of the computerized feedback game (16.3 and 23.7, with and without the game, respectively). It is suggested that game-based testing procedures may ensure more consistent results in the assessment of pediatric populations.

Introduction

Knowledge of the varaibility of a test is often overlooked in examining results of physiological responses to exercise. When comparing a number of studies and a variety of subjects, differences less than the test variabiltiy cannot be explained and apparent discrepancies in results may reflect random variations rather than experimental effects. Within investigations of test variability, technological and biological sources of error can be quantified. The Wingate anaerobic test (WAnT) has been described as sensitive enough to measure improvement or deterioration in performance (Bar-Or, 1983), yet its variability in children has not been documented. The extent to which children's performances vary from day to day provides useful information to experimenters assessing the reliability of test results. Given similar environmental conditions and training status, the key issue in variability of highly intense exercise in children such as the WAnT, may be motivation. Recently, exercise intensity was measured in 9-year-old boys during the use of an action pad video type game which had been placed on the floor. This game elicited an exercise response which was of a moderate to high intensity in terms of the relative percent of peak oxygen uptake (70.9%) (Greenbom and Saltarelli, 1991). It is surmised that computerized technology may provide an element of motivation which will facilitate optimal performances in child-based populations. In the present study, two investigations examined the variability in WAnT performances of children aged 6, 8, 10, and 12 years. The purpose of the first part of the study was to investigate the variability of children performing four WAnTs over a period of four weeks. The purpose of the second part of the study was to examine the effect that a computerized, on-screen game linked to pedal cadence, would have on the variability of performances in WAnT results of children.

Mathematically, variability is acknowledged as the mean coefficient of variation (C.V.=(S.D./X)*100). Partitioning the total variability into biological and technological fractions is also feasible. Technological error is determined from a series of calibration studies on factors identified as potential error sources of a non-environmental, equipment-based nature. The technological error can then be expressed in relation to the total variability and the remaining fraction is acknowledged as a biological source of variability (Coggan and Costill, 1984).

Methods

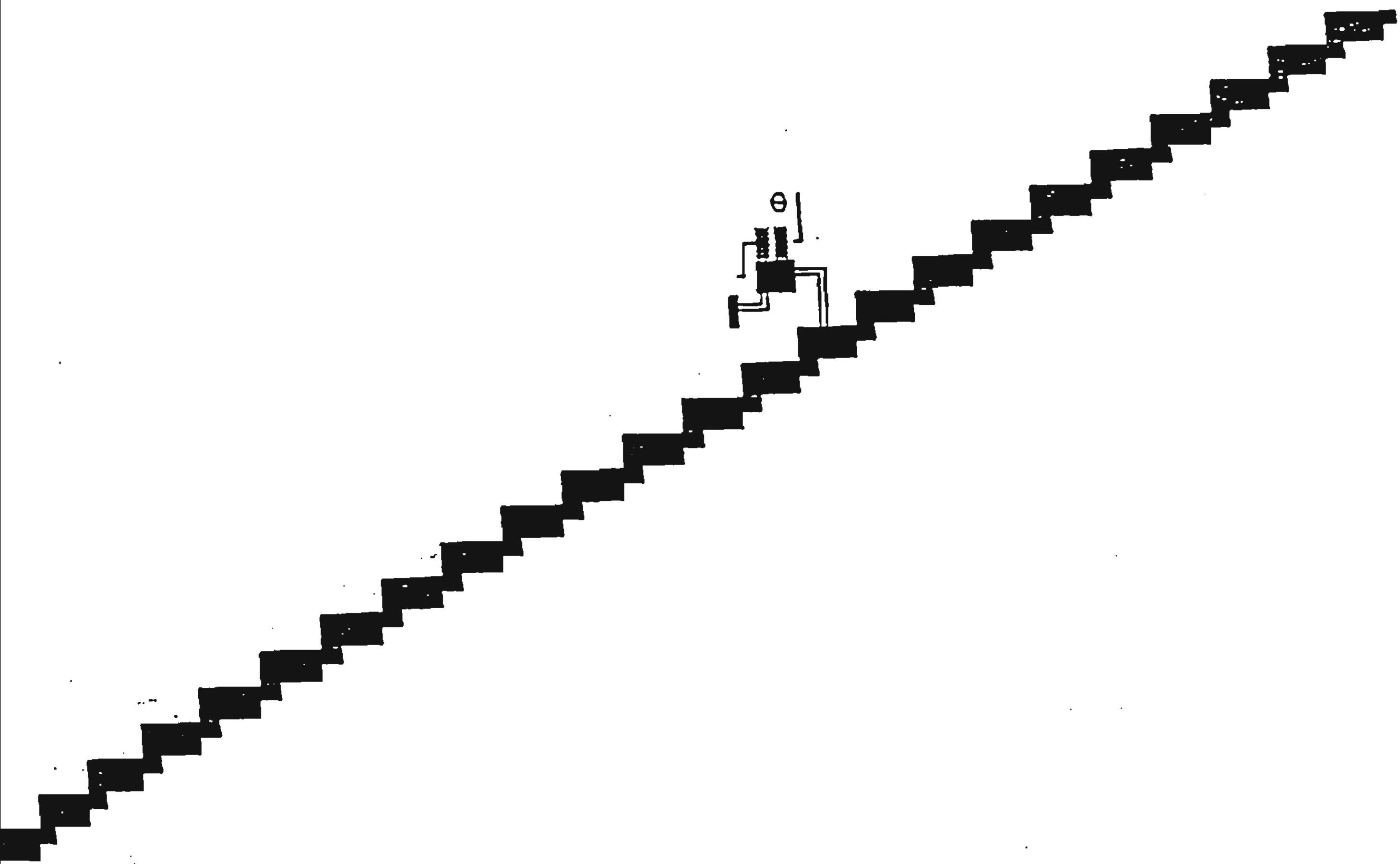
Four age groups of children were involved in parts one and two of the study (6, 8, 10, and 12 years). In part one 32 children (eight males in each age group) were recruited to participate in the study. In part two there were 20 children (five males in each age group). All children were volunteers from an inner suburban primary school. Table 5.1 outlines the descriptive characteristics of children involved in both parts of the study. It should be noted that not all the children in part two had participated in part one. Prior to the commencement of the study, parents and children were informed verbally and in writing of the experimental procedures. All children were familiar with cycling skills prior to the testing.

All testing was conducted on a modified Monark cycle ergometer as described in Chapter 3. The six year old children who could not comfortably maintain a pedal cadence while seated on the cycle ergometer were excluded from the study. Recently, Elias et al.(1991) demonstrated that efficiency of cycling in light weight children (26 to 47 kg in body mass) was not influenced by the use of shorter crankarm than 17.5 cm. The crankarm was therefore maintained at 17.5 cm for all age groups of children in the present study. Performance data were collected and analysed by an IBM computer.

In both parts of the study, 30 s all-out Wingate anaerobic tests were performed (Ayalon et al., 1974; Bar-Or, 1983; Coggan and Costill, 1984; Katch et al., 1982). Height and body mass of the subjects were recorded at the commencement of each study and the children were weighed again prior to each test. Tests were conducted on separate days. No more than seven days separated any two tests. The warm-up protocol used by the children has been previously described (Chapter Three). Fifteen seconds before the WAnT the children began unloaded cycling to help overcome inertial forces at the onset of the resistance which coincided with the commencement of the test. Children pedalled against resistances equivalent to 0.075 kp.kg.BM (4.4 $J \cdot kg^{-1}$ crank rev^{-1}) for the 30 s test. This represented mechanical work of 4.41J per pedal revolution per kilogram of body mass (Ayalon et al., 1974; Bar-Or, 1987). In all tests a similar amount of verbal encouragement was provided. Performance measures included; peak power [PP] (the highest mechanical power output in watts at any one tenth of a second over the 30 s test), mean power [MP] (the averaged mechanical output in watts over the 30 s), and fatigue index [FI%] (the difference between PP and the final power (P_{end}) expressed in relation to the peak power $[(PP-P_{end})/PP]*100$).

In part one of the study, the boys performed four WAnTs over a period of four weeks. In part two of the study the children were required to perform eight tests. These tests which involved four performances with the computerized game and four performances without the game, were conducted in randomised order. The game was based on the cadence of the flywheel as the child cycled. Projected onto the screen of the computer in front of the Monark cycle ergometer was a stick figure ascending a flight of stairs (Figure 5a). The faster the pedal cadence, the higher the figure climbed the stairs. As the child's pedal frequency declined, the task then became to maintain the figure at the highest possible level on the staircase.

Figure 5a : The figure on the computer screen which ascended the stairs at a rate commensurate with pedal frequency as a means of performance feedback



Prior to testing the potential sources of technological variability were identified. An error factor for the applied force was calculated by suspending a series of calibration weights from the force transducer attached to the cycle ergometer. Errors attributed to the revolution rate were determined from tests using a signal generator with frequencies simulating known revolution rates and subsequently recording the output of the digital frequency meter. The timing device was identified as another potential error source. A start/stop signal was used so that the computer clock and a Lafayette milliseconds clock, placed in parallel were started and stopped by the same trigger pulse edge. The potential sources of technological error were combined and this total was subtracted from the total measured variability with the resultant net providing an index of biological error.

Data from the two parts of the study were subjected to three main analyses: Mean coefficients of variance (C.V.) were calculated for each subject from the standard deviations and means in performances of the series of four tests in the first study and four tests with and without the computerized game in part two of the study. C.V. values were obtained from PP, MP, and FI% performances. A series of univariate ANOVAs (BMDP, 1985) were conducted on performance and variability data. Part one of the study involved a 4 x 4 ANOVA for age and tests. Data from part two of the study were analysed using a 4 x 2 x 4 ANOVA for age, presence or absence of the game, and the four tests within each of these two conditions. Newman-Keuls post hoc analysis tests were used where appropriate (Kirk, 1968).

Results

The descriptive profiles of the children in this study are presented in Table 5.1. The 6-yr-old children were significantly smaller in height, mass and body surface area than each of the older groups.

No significant interactions were reported in data for within age and across the four test performances in all measured variables from the first part of the study (Figure 5b, Appendix 2a-e). Main effects analysis found significant age effects in performances of PP and MP ($\underline{F}(3,28) = 22.79$, $\underline{p} \leq 0.001$, and $\underline{F}(3,28) = 22.35$, $\underline{p} \leq 0.001$, respectively). Newman-Keuls post hoc analysis identified that the significant differences in the PP. and MP centred around much less powerful performances of the 6 year old group compared to the three older groups of children (Table 5.2).

Significant differences remained when PP and MP were expressed in relation to body mass (relPP. and relMP) ($\underline{F}(3,28) = 6.80$, $\underline{p} \leq 0.001$ and $\underline{F}(3,28) = 8.47$, $\underline{p} \leq 0.004$, respectively). FI% was not significantly different among the age groups ($\underline{F}(3,28) = 2.12$, $\underline{p} \leq 0.12$). Analysis of the variability data from the four tests in part one of the study, revealed no significant main effect for age in PP, MP, and FI% performances (Table 5.3). With age collapsed the averaged C.V. values were 7.3, 6.8, and 26.7%.

Table 5.1 Descriptive characteristics of male children in parts one and two of the study.

n	Age (yr)	Body mass (kg)	Height (cm)	BSA* (m^2)
Part One				
8	12.2	36.8	143.6	1.21
	(0.0)	(0.9)	(2.6)	(0.01)
8	10.5	34.2	142.5	1.17
	(0.1)	(2.0)	(2.0)	(0.01)
8	8.4	30.3	135.6	1.07[a]
	(0.0)	(0.8)	(2.3)	(0.01)
8	6.6	24.5[abc]	121.6[abc]	0.99[abc]
	(0.1)	(0.7)	(1.0)	(0.01)
Part Two				
5	12.8	41.9	152.1	1.36
	(0.0)	(1.9)	(1.4)	(0.02)
5	10.3	34.0	143.4	1.17[a]
	(0.1)	(1.8)	(1.2)	(0.01)
5	8.8	33.6	139.0[a]	1.08[a]
	(0.1)	(2.4)	(4.1)	(0.01)
5	6.6	23.2[abc]	126.4[abc]	0.92[abc]
	(0.1)	(0.7)	(1.2)	(0.02)

M±SEM

*(Du Bois and Du Bois, 1916)

'a' denotes significantly less than 12 yr. old males

'b' denotes significantly less than 10 yr. old males

'c' denotes significantly less than 8 yr. old males

Figure 5b: WAnT performances of male children across four tests; (i) peak power [w], (ii) mean power [w] and (iii) FI[%].

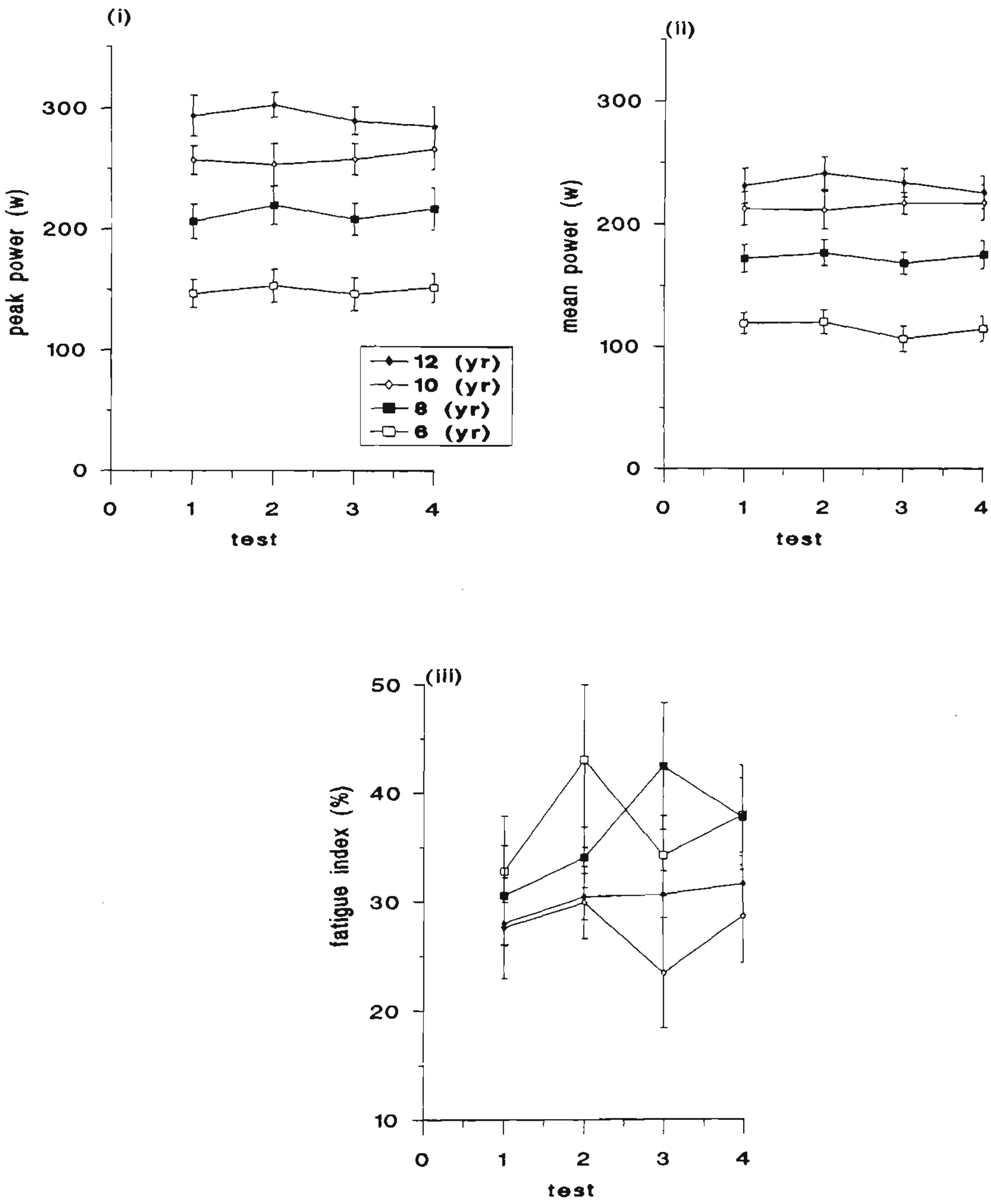


Table 5 2: Performance data from children in part one of the study.

Age (yr)	PP (w)	MP (w)	relPP ($w \cdot kg^{-1}$)	relMP ($w \cdot kg^{-1}$)	FI (%)
12	294	233	8.3	6.8	30
	(14)	(13)	(0.2)	(0.3)	(2)
10	257	214	7.1^{a}	5.9	27
	(15)	(13)	(0.2)	(0.4)	(4)
8	231	173	7.0^{a}	5.2	36
	(15)	(11)	(0.3)	(0.2)	(4)
6	150^{abc}	115^{ab}	6.2^{a}	4.7^{a}	37
	(13)	(10)	(0.4)	(0.4)	(6)

M±SEM

'a' denotes significantly less than 12 yr. old males

'b' denotes significantly less than 10 yr. old males

'c' denotes significantly less than 8 yr. old males

Table 5.3: Mean coefficients of variation (C.V.) of children in part one of the study

Age (yr)	C.V. from PP	C.V. from MP	C.V. from FI%
12	4.8	5.8	17.7
	(0.7)	(1.5)	(2.5)
10	9.0	8.4	36.5
	(1.4)	(1.3)	(9.8)
8	8.0	4.9	27.1
	(1.2)	(0.8)	(5.9)
6	7.4	8.0	25.6
	(1.4)	(2.5)	(6.4)

M±SEM

Table 5.4: Performance data from children in part two of the study

Age (yrs	Peak power (w)		Mean power (w)		relative peak power ($w \cdot kg^{-1}$)		relative mean power ($w \cdot kg^{-1}$)		Fatigue index (%)	
	with	without	with	without	with	without	with	without	with	witho
12	363	360	282	275	8.5	8.5	6.6	6.5	43	44
	(25)	(23)	(24)	(19)	(0.4)	(0.4)	(0.4)	(0.1)	(3)	(4)
10	268[a]	257[a]	215[a]	208[a]	7.6[a]	7.4[a]	6.1[a]	5.9[a]	[illegible]	30
	(26)	(22)	(18)	(14)	(0.5)	(0.4)	(0.3)	(0.3)	[illegible]	(4)
8	221[a]	213[a]	175[a]	171[a]	7.0[a]	6.7[a]	5.6[a]	5.4[a]	[illegible]	36
	(19)	(18)	(15)	(16)	(0.4)	(0.3)	(0.4)	(0.3)	[illegible]	(3)
6	134[abc]	131[abc]	103[abc]	99[abc]	5.6[abc]	4.6[ab]	4.3[ab]	4.2[ab]	[illegible]	39
	(13)	(13)	(9)	(9)	(0.5)	(0.5)	(0.3)	(0.3)	[illegible]	(4)

M±(SEM)

'a' denotes significantly less than 12 yr. old males

'b' denotes significantly less than 10 yr. old males

'c' denotes significantly less than 8 yr. old males for PP, MP, and FI%, respectively.

Performance results from the second part of the study with the feedback game have been presented in Table 5.4 and Appendices 2f-j. Main effects analysis indicated that significant differences in PP, MP, relPP, and relMP were age-related. Newman-Keuls post hoc analysis, revealed that significant differences were again present in the smaller scores of the 6-yr-old group compared to the older children. Significantly more powerful performances of the 12-yr-old boys compared to 8 and 10 year old children in PP, MP, and relMP were also reported from this analysis (Table 5.4). Main effects analysis on performances of WAnTs with and without a computerized game demonstrated small improvements in performance scores for PP (from 240±19 to 246+20 w), MP (from 188±14 to 194±16 w), relPP (from 7.0±0.4 to 7.4±0.4 $w \cdot kg^{-1}$), and relMP (from 5.5±0.2 to 5.6±0.3 $w \cdot kg^{-1}$). These changes represent relative percent improvements of 2.5, 2.6, 5.5, and 1.8, for PP, MP, relPP, and relMP, respectively. Main effects analysis on the variability of performances in the presence of the computerized game was not significantly different in PP and MP performances ($F(1,16) = 3.75$, $p \leq .07$, $F(1,16) = 3.76$, $p \leq .06$, respectively) (Table 5.5). However, there was a significant reduction in the variability of all children's performances in the FI% ($F(1,16) = 9.27$, $p \leq .001$). In both parts of the study, no significant differences were apparent in one-way ANOVAs for between-trial differences in performance and variability data from each of the age groups.

The sum of the identified technological sources of error was 1.2%. Total variability was then divided into biological and technological partitions. Table 5.6 presents the variability of performances in PP, MP, and FI% in total and with the biological and technological error expressed in relation to the whole variability. Table 5.6 also contains data from other available studies (Coggan and Costill, 1984; Katch et al., 1982) Technological sources of variability in all of the studies are presented in Table 5.6. As a consequence of the low vlaues of technological error in the present study, its influence on the reported C.V. values may be regarded as negligible.

Table 5.5: Mean coefficients of variation (C.V.) of children in part two of the study

Age	C.V.(PP)		C.V. (MP)		C.V. (FI%) **	
(yr)	with	without	with	without	with	without
12	6.2	7.7	5.6	6.6	9.2	18.6
	(1.3)	(8.4)	(0.8)	(0.9)	(1.1)	(5.5)
10	6.8	8.4	5.4	6.5	16.6	32.5
	(0.8)	(1.3)	(0.7)	(1.3)	(4.1)	(6.4)
8	6.3	7.4	5.1	8.2	15.8	20.0
	(1.0)	(1.0)	(1.0)	(1.2)	(2.4)	(1.4)
6	6.1	8.7	6.4	8.3	23.6	23.6
	(0.5)	(1.5)	(0.7)	(2.2)	(2.2)	(3.1)

M±SEM

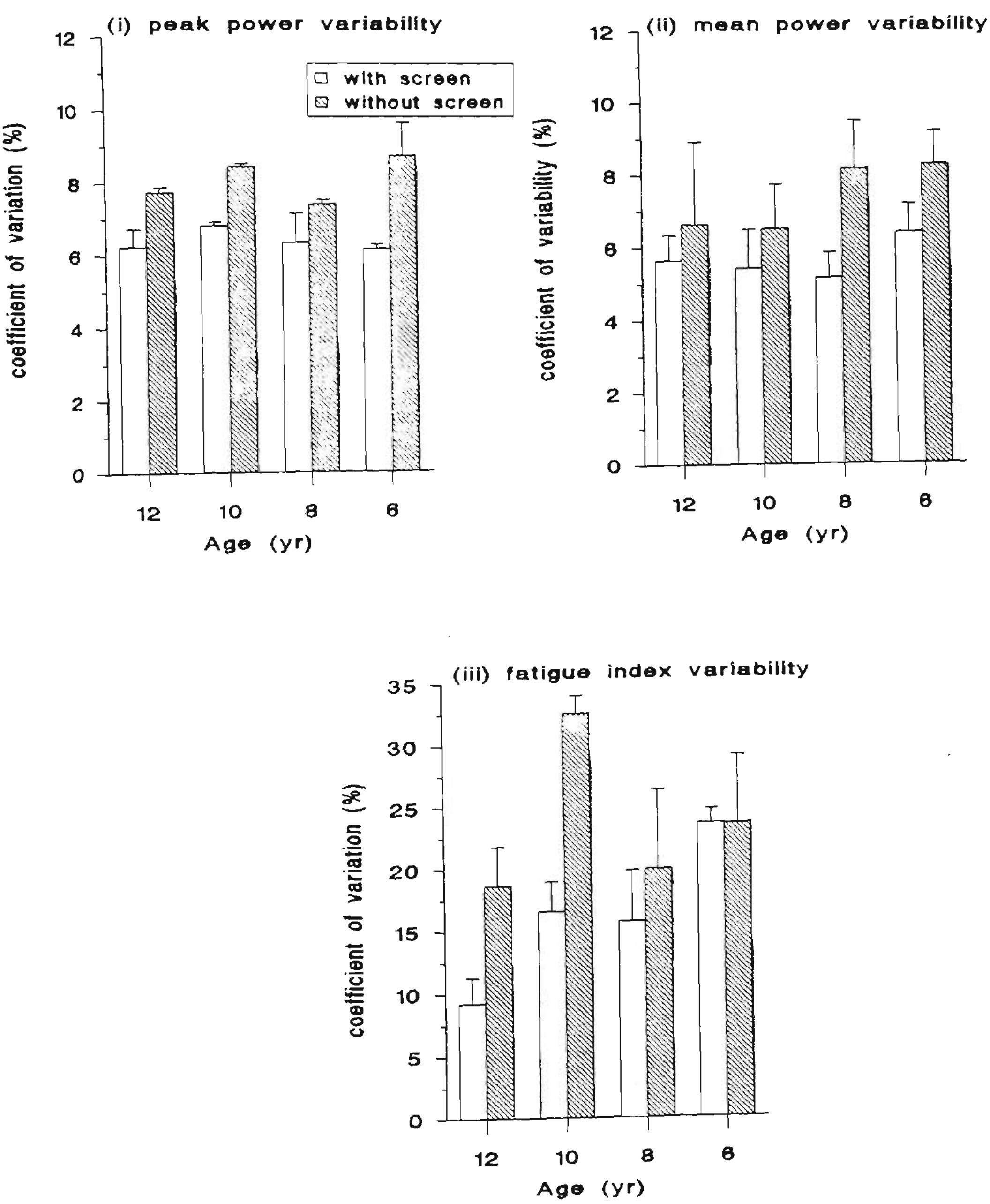
**significant main effect differences in FI% with and without the screen when age was collapsed ($p=0.006$)

Discussion

There were two major findings from this study. The first major finding was that the C.V. obtained from PP and MP performances of the children tested were not large. C.V. values for peak and mean power performances of children were compared favorably to previously reported variability in adults obtained under similar conditions (Table 5.6). The relatively low variability in the children from the present study could however be associated with the non randomised sample of children who were all volunteers from the one population. It may be speculated that variability from a randomised sample of children of similar ages may have been greater. Cycling ability was not tested in the subjects in this study. Variability may have been further reduced if subjects had been accepted into the study on the basis of a particular skill ability in cycling. However, Bar-Or's (1987) summary of several studies which examined the test-retest reliability data from WAnTs on children produced correlation coefficients which were generally above .94. Therefore the observed low C.V. scores from PP and MP performances of children in the present study may be somewhat expected. Because C.V. protocol necessitates more than the two tests required for correlation coefficient scores, variability tests may be a stronger index of the accuracy of test performances.

Variability of FI% of children and adults was much higher than the variability of performances in PP, and MP. It was somewhat expected that variability in this measure was not as stable as in PP, and MP. FI% is derived from the quotient of two independent measurements of PP and final power which themselves may vary substantially and subsequently variance may become greater when expressed in combination with each other. However variability in the FI% was disproportionately greater in the children (26.7% in present study) than adults (10.3%, Coggan and Costill, 1984). Although the FI% variability of children remained greater than adults in both of the present studies, significant improvement was made in the second part of the study. Therefore the second major finding of this research study was the significant decrease in the variability of the FI% and improvements in several of the physical performance measures when motivation was provided in the form of a computerized feedback game (Figure 5c). The success of a computerized game in decreasing the variability in FI% may be associated with previous findings on children's motivation for initial and continued participation in physical activity. Weiss and Petlichkoff (1989) summarised the four main motivational reasons for participation of children in activity as; competence in skill acquisition, social affiliations, fitness, and fun. Perhaps the presence of a game in part two of the study offered the children enough fun to significantly promote more consistent performances than when they performed the WAnTs in the absence of a game. Katch et al. (1982) believed that motivation played an important role in the variability of aerobic performances in adults. Recently, literature on children in laboratory situations has described incentives in the form of 'laboratory toy shops' to motivate children towards optimal physiological performances (Shuleva et al., 1990). Geron and Inbar (1980) experimented with seven types of motivation (audience presence, individual competitions, group competitions, punishment, reward, group association, and social responsibility) on adult subjects performing the WAnTs and reported no significant performance effects from the motivational stimuli provided by cognitive information. Bar-Or (1987) speculated that motivation focusing on emotional arousal would be more likely to affect the peak rather than mean power performance in WAnTs. In the present study, the peak and mean power performances of the children were not affected by the presence of the computerised game. The nature of the computerised game in the present study differed from the seven types of cognitive information provided by Geron and Inbar (1980). Motivation in the present study involved an 'on-screen' visual form of feedback which was perhaps most appropriately presented to the children under the guise of a game. McLean and Lafortune (1988) reported a significant improvement in the performance of elite Australian cyclists following the use of a computerized feedback program. The authors devised a feedback program that allowed cyclists to eleviate inefficiencies which occurred by having them adjust any negative torque in the recovery phase of their pedal stroke. Use of a computerized

Figure 5c: Variability in (i) Peak power, (ii) mean power and (iii) Fatigue Index values from performances with and without the presence of a feedback game.



game in the present study may therefore have injected an enhanced element of fun into the WAnTs and may also have improved performance through the addition of a visual feedback stimulus.

Within the performance data of the study, the 6-year-old children demonstrated significantly less powerful performances than the older children. In relation to previously published performances of 6-year-old children, the males in the present study have performed comparably. Van Praagh et al. (1989) conducted WAnTs on 7-year-old boys and reported MP, and relMP performances which were 123±9 w, and 4.7±0.2 $w.kg^{-1}$, respectively, which compares well with MP and relMP performances in 6-year-old males from the two parts of the present study of 101, and 115 w and 3.5± and 4.7± $w.kg^{-1}$, (for parts one and two of the study), respectively. Part one of the study also reported significantly less powerful performances in 6-year-old children compared to older groups of children performing WAnTs against varying resistances. Possible explanations for these observations in 6-year-old children may be found in any number of sources such as, immaturity of cycling ability, inferior dimensional and functional characteristics of the active muscle, decreased anaerobic energy supplies and tolerance, and, or a difference in the 6-year-old child's psychophysiological approach to the testing. However, it should be noted that within the context of the present study, the variability in the performances of 6-year-old males in the present study did not differ significantly from the three older groups of children. Therefore the unknown factors contributing to the less powerful performances of 6 year old children in the present study appeared to be consistent between subjects, and within performances.

In summary, it was determined that the primary source of variance in the WAnT performances of male children aged 6, 8, 10, and 12 years was of a biological nature. Technological variability was negligible. Total variance in PP (7.3, and 7.2%), and MP (6.7, and 6.5%), in parts one and two of the study, respectively compared favourably with the variance reported from adults (Coggan and Costill, 1984) performing a similar task (6.7, and 5.4% for PP and MP, respectively). However, the variabilities in FI% in the children from parts one and two of the study (26.7 and 20%, respectively) were substantially higher than 10.3% previously reported for adults, (Coggan and Costill, 1984). Experimenters observing scores in pre and post training studies, or in protocols requiring several test repetitions from this group of children would need to acknowledge the obtained margins of variablility in accounting for these results. It is suggested that combining the technology of visual feedback with the challenge and enjoyment of a computer-based game during work with children in the present study had an effective impact on the consistency of the WAnT results.

Table5.6: Comparison of the C.V. values of the present study to results from previous studies.

Study	Nature of Test	Total	Variability Biological	Technological
Katch et al., (1982)	VO_2 max	5.6	90	10
Coggan and Costill (1984)	30 sec (FITRON™)			
	PP	6.7	76	24
	MP	5.4	69	31
	FI%	10.3	85	15
Present study (part one)	WAnT			
	PP	7.3	83	17
	MP	6.7	82	18
	FI%	26.7	95	5
Present study (part two)	WAnT 'without screen'			
	PP	8.1	85	15
	MP	7.4	84	16
	FI%	23.6	95	5
	WAnT 'with screen'			
	PP	6.4	81	19
	MP	5.6	80	20
	FI%	16.3	93	7

M±SEM

Chapter Six

Study Three

An Examination of the Anaerobic Capacity of Children using Maximal Accumulated Oxygen Deficit.

An Examination of the Anaerobic Capacity of Children using Maximal Accumulated Oxygen Deficit.

Abstract

The purpose of this study was to determine the anaerobic capacity of children using the maximal accumulated oxygen deficit technique (AOD). Eighteen healthy children; nine boys and nine girls with a mean age of 10.6 years volunteered as subjects. Peak oxygen uptake and a series of submaximal steady state oxygen uptake tests were conducted against progressive constant workloads on a CYBEX™ cycle ergometer. Supramaximal workloads were predicted from the linear regression of submaximal steady state workloads and oxygen uptakes. Three supramaximal constant power tests were conducted at 90 rpm. The supramaximal workloads were predicted to equal 110, 130, and 150% of peak oxygen uptake. Univariate 2 X 3 ANOVAs were conducted on data. A significant interaction indicating superior performances in males compared to females occurred when the accumulated oxygen deficit data were expressed in absolute and relative terms (litres and $ml \cdot kg^{-1}$, respectively). The profile of accumulated oxygen deficits across the three intensities indicated a downward shift in the girls responses between the 110 and 150% supramaximal tests. This trend was not evident in the male responses. The accumulated oxygen deficits, expressed in relative terms, determined at 110, 130, and 150% for males and females were 35.39±4.3, 37.1±3.7, 36.8±3.2, and 40.4±2.4, 37.8±2.2, 31.8±2.3 $ml \cdot kg^{-1}$, respectively). The response pattern in the males is similar to that reported previously in adults. Intraclass correlations conducted on test-retest data indicted that compared with the males, the reliability of the females in the accumulated oxygen deficits in litres and $ml \cdot kg^{-1}$ was poorer (0.87, 0.79, and 0.95, 0.57, respectively.)

Introduction

Protocols for the assessment of the anaerobic characteristics of children have been many, and varied. Vertical jumps, stair climbs, force-velocity and short-term all-outcycle tests, have all been utilised for the assessment of instantaneous, anaerobic power (Vandewalle et al., 1987). In previous years, anaerobic characteristics have been most popularly defined through the use of the Wingate anaerobic test (WAnT) (Bar-Or, 1983, 1987; Inbar and Bar-Or, 1986; 1975). Substantial discussion has centred on the variability of results depending upon the protocol adopted for the anaerobic testing using WAnTs (Inbar and Bar-Or, 1975; Jacobs et al., 1983; McKenna et al., 1987; Van Praagh et al., 1990; Vandewalle et al., 1987). WAnTs have been used to determine peak and mean power outputs but may not reveal a true anaerobic capacity because the recommended 30 s duration of the exercise test has been described as insufficient to exhaust the capacity of anaerobic energy sources (Saltin, 1990; Vandewalle et al., 1987).

Developmental trends, effectiveness of training or treatment interventions, and talent identifications may all be obtained from testing protocols involving maximal capacity performances. A new method for determining the maximal capacity of anaerobic energy sources has only recently been developed. It is termed the accumulated oxygen deficit (AOD) method (Hermansen and Medbϕ, 1984; Medbϕ, 1991; Medb ϕ and Burgers, 1990; Medbϕ et al, 1988; Medbϕ and Tabata, 1989). A detailed description of the methods and the underlying assumptions have been outlined previously (Hermansen and Medbϕ, 1984; Medbϕ, 1991; Medbϕ and Burgers, 1990). Briefly, the AOD technique predicts an accumulated oxygen demand for supramaximal anaerobic exercise for each subject by extrapolating data from the linear relationship between submaximal steady state workrates and oxygen uptake. Medbϕ et al. (1988) stated his preference for the term 'accumulated oxygen demand' which indicated an 'amount' rather than a 'rate' of energy release. The term 'accumulated' is synonymous with the time taken to exercise to exhaustion. Medbϕ (1991) expressed actual accumulated oxygen demand as the sum of accumulated oxygen uptake and accumulated oxygen deficit. Therefore the accumulated oxygen deficit was calculated from the difference between the predicted accumulated oxygen demand and the accumulated oxygen uptake.

Saltin (1990) recently reviewed the theoretical objections to all methods available for determining the capacity of the anaerobic system. Measuring anaerobic capacity from blood lactate samples was questioned on the grounds of an assumed equilibrium between lactate from muscle and blood, variability of dilution space for lactate, and rapidity of the rate of lactate efflux. Estimating anaerobic capacity from retrospective measurements of oxygen debt was also questioned by Saltin (1990) because of the number of non metabolic demands on oxygen uptake during post exercise recovery periods. In a discussion of the AOD method of determining anaerobic capacity, he challenged the validity of extrapolating aerobic efficiency from submaximal into supramaximal conditions. He documented the problems he had in accepting that the true aerobic cost of supramaximal exercise would not be underestimated for highly intense exercise conditions. Saltin (1990) believed that additional demands were placed on the body during exercise at extreme intensities which would be ignored in a system extrapolating from submaximal into supramaximal conditions. Saltin (1990) stated his reservations about the method but also suggested that to date the AOD method was the most quantifiable and valid method available for the determination of anaerobic capacity. The method is preferred because it does not assume the one efficiency for all subjects (i.e., it measures individual efficiencies through a range of submaximal workrates), and because it uses more than one data point from which predictions are made for the aerobic cost of supramaximal exercise (Medbφ, 1991). To date, the available research on anaerobic capacity using the maximal AOD method has all been conducted on adult populations. The capacity of anaerobic performances in children warrants further investigation. The purpose of this study was to quantify the anaerobic capacity of children using the maximal AOD technique.

Methods

Eighteen normal, healthy children (nine boys; mean age 10.6 years, and 9 girls; mean age 10.7 years) from an inner suburban primary school volunteered as subjects for the study with their parents' consent. Of the children, only two of the males were involved in organised sporting activities (less than two hours per week) outside of school hours.

The children attended the laboratory on 10-12 occasions. Following a familiarization visit to the laboratory, all children performed a peak oxygen uptake test on a CYBEX™ electronically-braked constant load cycle ergometer (Met 100, Lumex). The peak oxygen uptake protocol required that twenty-five watt increments were imposed every minute until volitional exhaustion and, or criteria for peak performance were observed (Zwiren, 1989). To determine accumulated oxygen deficit subjects performed a series of steady state submaximal tests. This involved 4 or 5 submaximal workrate tests within the range of 40 and 72% of peak oxygen uptake for 6-8 minutes duration at a pedal cadence of 90 rpm. Steady state oxygen uptakes (VO_2) for these submaximal workrates were obtained from a non-linear exponential equation (KaleidaGraph, 1989). Steady state submaximal testing involved no more than two tests on the one day, with at least 20 minutes of rest between each test. The individual power-O_2 relationship was then determined from data from the 4-5 steady state tests using a standard, least squares linear regression equation ($VO_2 = a + b[\text{workrate}]$).By extrapolation this equation then enabled the calculation of the predicted oxygen cost of the mean all out isokinetic effort. (See also Appendix 3a). These equations were used to predict supramaximal workloads representing 110, 130 and 150% of peak VO_2.

Three supramaximal cycling tests were conducted at workloads predicted to represent 110, 130 and 150% of the peak oxygen uptake. The children were required to maintain a pedal frequency of 90 rpm until voluntary exhaustion or test termination when the pedal frequency decreased to 70 rpm. The test-retest reliability of the children's performances was examined by randomly assigning the repetition of one of the supramaximal intensity tests. During the supramaximal tests expired gases were collected in Douglas Bags and analysed as described in Chapter Three.

Data were statistically treated using independent t-tests for mean differences in descriptive data, one-way ANOVAs for within group differences in performance data during supramaximal tests such as oxygen deficit, RER, and time to exhaustion, and 2 X 3 ANOVAs for interactions between the two sexes and the three supramaximal intensity performance data means (BMDP, 1985). Newman-Keuls post hoc analysis tests were applied wherever appropriate. The test re-test reliability of the supramaximal performance data was determined from calculations of intraclass correlation coefficients (R). The 0.05 level of significance was accepted for all testing.

Results

Descriptive and peak oxygen uptake data for the children are presented in Tables 6.1 and 6.2. A significant difference between the sexes was observed in the relative peak oxygen uptake scores ($ml \cdot kg^{-1} min^{-1}$) of the boys (54.5 $\pm$2.5) and the girls (43.2 $\pm$1.1) [$\underline{t}$ (11) 4.18, $\underline{p} \leq 0.002$].

AOD scores were obtained from the differences between the theoretical aerobic demands and the accumulated oxygen uptakes (Figure 6a). A series of 2 X 3 ANOVAs were conducted on the AOD data to determine if any sex differences existed across the three supramaximal intensities. A significant interaction occurred between sex and intensity when the AODs were expressed in litres, ($\underline{F}(2,32) = 3.38$, $\underline{p} \leq 0.046$). This is evident in the downward trend in the female data between 110 and 150% in the absolute AOD results (litres) (Figure 6b (i) and Appendix 3b). However, simple main effects analysis revealed no significant differences between the sexes for accumulated oxygen deficits (litres) for specific intensities calculated to represent 110, 130 and 150% of maximal areobic capacity (p values of 0.07, 0.19, and 0.95, respectively).

When AOD was expressed in relation to body weight ($ml \cdot kg^{-1}$) a significant interaction also occurred between sex and intensity ($\underline{F}(2,32) = 3.52$, $\underline{p} \leq 0.036$). Figure 6b (ii) demonstrates the significant downwards shift in the relative accumulated oxygen deficit data ($ml \cdot kg^{-1}$) of the females, but not the males. Again, results of the simple main effects analysis did not identify a specific intensity at which the interaction occurred ($p \leq 0.32$, 0.88, and 0.23 for the 110, 130, and 150% intensities, respectively).

A number of one-way ANOVAs were also conducted within each sex and across the intensities (Table 6.3). No significant differences were reported in the two expressions of AOD results (litres and ml·kg^{-1}) for males across the three intensities ($\underline{F}(2,32) = 0.12$, $\underline{p} \leq 0.885$, and $\underline{F}(2,32) = 0.26$, $\underline{p} \leq 0.775$). However, the responses of the females indicated significant differences among the means of AOD values at the three intensities. Post hoc analysis tests demonstrated that the absolute AOD results (litres) for females at 110% were significantly higher than those at 130 and 150% intensity, and that at 130% the AOD were also significantly higher than that at 150% (1.71±0.21, 1.59±0.12, and 1.36±0.12, for 110, 130, and 150%, respectively). When the accumulated oxygen deficit data for the females were expressed in relative terms, significant differences were reported between 110 and 150%, and 130 and 150% intensities (40.4±2.3, 37.8±2.2, and 31.8±2.2 ml·kg^{-1} for 110, 130, and 150%, respectively). The data for accumulated oxygen deficits fell within a wide range. In females, for example, at 110% intensity, the AOD scores obtained ranged from 29.4 to 47.0 ml·kg^{-1}.

No significant interaction was reported between sexes for the time taken to exhaustion during the three supramaximal intensity tests (Table 6.3 and Appendix 3b). Main effects analysis demonstrated that the durations of the three tests for all children were significantly different from each other (124±13, 74±6, and 48±3 seconds for the 110, 130 and 150% intensities, respectively) ($\underline{F}(1, 16) = 3.96$, $\underline{p} \leq 0.22$).

Table 6.1: Descriptive characteristics of children in Study Three

Sex	Age (yrs)	Mass (kg)	Height (cm)	BSA* (m^2)
m	10.6	37.21	144.6	1.23
	(0.2)	(1.25)	(1.8)	(0.02)
f	10.6	41.38	149.9	1.38
	(0.3)	(2.60)	(3.5)	(0.05)

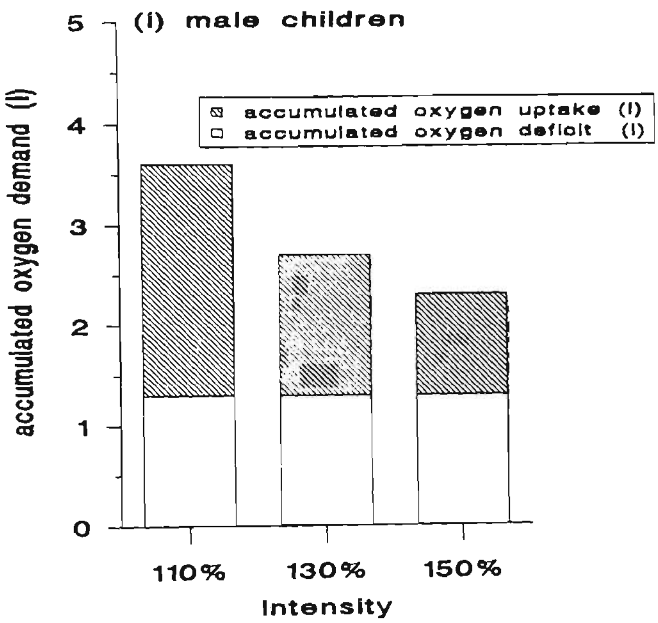
* Body Surface Area (m^2) [Du Bois and DuBois, 1916]

Table 6.2: Peak oxygen uptake profile of children in Study Three.

Sex	VO_2 max (l.min^{-1})	VO_2 max (ml·kg^{-1}·min^{-1})	HR (bpm)	RER max	WL max (w)
m	1.99	53.87	199	1.13	172
	(0.05)	(2.30)	(2)	(0.01)	(4)
f	1.72	43.32^a	197	1.11	165
	(0.12)	(1.08)	(2)	(0.02)	(11)

'a' denotes significant difference between sexes M±SEM

Figure 6a: Partitioning of accumulated oxygen demand (litres) in to accumulated oxygen uptake and accumulated oxygen deficit of (i) male and (ii) female children.



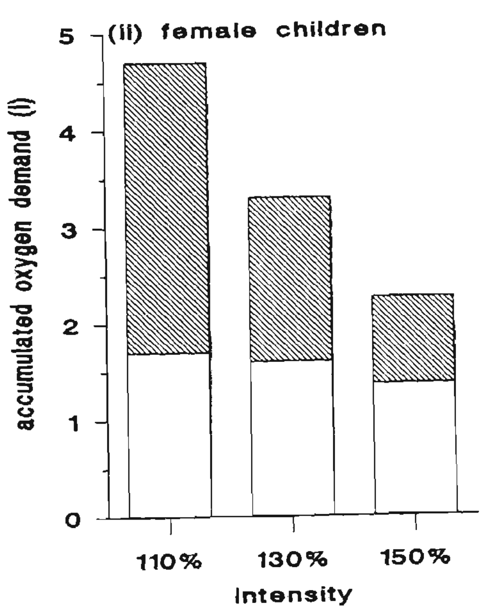
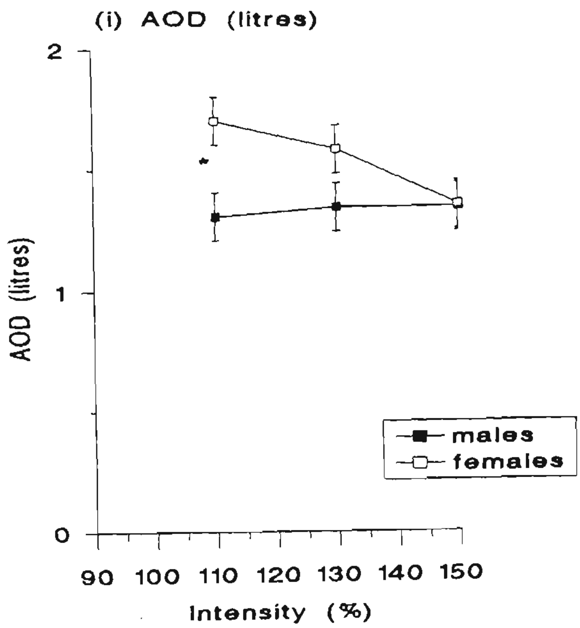
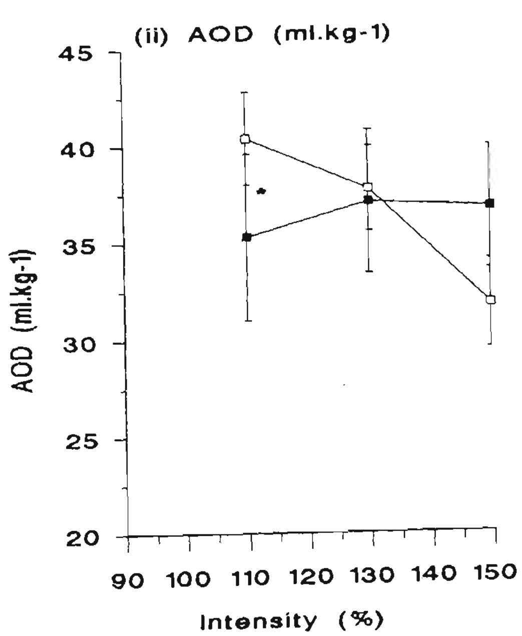


Figure 6b: Responses of male and female children to three supramaximal intensities in accumulated oxygen deficits which were measured in (i) litres and (ii) ml·kg^{-1}





* denotes significant interaction

Table 6.3: Accumulated oxygen deficit data from 18 male and female children

Variable	Sex	Intensity 110%	130%	150%
Accumulated O_2 deficit (litres)	m	1.31	1.35	1.35
		(0.1)	(0.1)	(0.15)
	f	1.71	1.59[a]	1.36[ab]
		(0.1)	(0.1)	(0.1)
Accumulated O_2 deficit ($ml \cdot kg^{-1}$)	m	35.3	37.1	36.8
		(4.3)	(3.7)	(3.2)
	f	40.4	37.8	31.8[ab]
		(2.4)	(2.2)	(2.3)
Exercise Duration (s)	m	102	62[a]	43[a]
		(20)	(10)	(4)
	f	146	86[a]	52[ab]
		(16)	(6)	(3)
% Aerobic Contribution	m	59.8	46.5[a]	38.7[ab]
		(3.1)	(3.8)	(1.9)
	f	63.4	52.6[a]	43.4[ab]
		(3.0)	(2.2)	(1.7)

M±SEM

`a' denotes significantly different from 110%

`b' denotes significantly different from 130%

$p \leq 0.05$

The relative percent of the aerobic energy contribution to performance is calculated by expressing the accumulated oxygen uptake as a percentage of the predicted accumulated oxygen demand for that intensity. The percentage of anaerobic contribution is the difference between the total oxygen demand (100%) and the calculated percentage of aerobic contribution measured during supramaximal exercise. No significant interaction between sex and intensity could be reported for the percentage of the aerobic energy contribution (Appendix 3c). The duration of the test and the percentage of aerobic contribution during the tests were linearly related. The aerobic contributions for the 110, 130, and 150% supramaximal intensity tests which had mean exercise to exhaustion times of 123, 73, and 47 seconds were 62±2, 50±2, and 41±1%, respectively (Table 6.3). (See also Appendix 3d)

Table 6.4: Rates of energy release across three supramaximal intensities from male and female children.

Rate	110%		130%		150%	
($ml \cdot kg^{-1} \cdot s^{-1}$)	m	f	m	f	m	f
Total energy demand rate	0.98 (0.05)	0.86 (0.03)	1.25 (0.11)	0.93 (0.09)	1.45 (0.11)	1.06 (0.03)
O_2 Uptake rate	0.65 (0.03)	0.52 (0.08)	0.56 (0.02)	0.50 (0.06)	0.55 (0.30)	0.46 (0.08)
AOD rate	0.39 (0.06)	0.29 (0.07)	0.67 (0.10)	0.45 (0.08)	0.88 (0.10)	0.60 (0.03)

M±SEM

Table 6.5: Intraclass correlation coefficient values (R) on the test re-test data of supramaximal exercise responses.

Sex	Accumulated oxygen deficit (litres)	Accumulated oxygen deficit ($ml \cdot kg^{-1}$)	Exercise duration (s)
ICC males (n=9)	.81	.92	.81
MS (between) (df=1)	0.20	210.8	1028
MS (within) (df=8)	0.02	9.2	134
ICC females (n=10)	.79	.55	.74
MS (between) (df=1)	0.57	135.9	1101
MS (within) (df=8)	0.07	39.2	160

ICC=Intraclass correlation coefficient

The rates at which energy was released are determined by dividing the accumulated oxygen demand, the accumulated oxygen uptake, and accumulated oxygen deficits by the duration of each test ($ml \cdot kg^{-1} \cdot s^{-1}$, (Medbϕ and Tabata, 1989). Table 6.4 and Appendix 3d demonstrate that as supramaximal exercise duration increased, the total energy demand and anaerobic energy release declined. As duration decreased, the rate of anaerobic energy release was increased.

Intraclass correlation coefficients (R) were conducted on the test-retest exercise data (Table 6.5). The results demonstrated that reliability was better in the males than the females, with the 'R' values from the accumulated oxygen deficits in $ml \cdot kg^{-1}$ in males and females being 0.92 and 0.55, respectively. Table 6.6 also displays a larger mean square within-subject variance in the females than the males in each of the performance variables.

Discussion

The significant interaction between the sexes for accumulated oxygen deficits (litres and ml·kg^{-1}) is difficult to explain. A significant downward trend in the accumulated oxygen deficits across intensities occurred in the females but not the males. The AOD data from the females in the present study could indicate that the true AOD value was perhaps refelected in the 40.39 ml.kg^{-1} observed at the 110% intensity. RER values for the females across the three supramaximal intensity tests were significantly and inversely related to intensity (1.14, 1.11, and 1.02 for 110, 130, and 150%, respectively). This was not the case for the male data, which recorded RER values of 1.03, 1.02, and 0.95 for 110, 130, and 150% intensity tests, respectively. Peak heart rate responses in the females were also significantly and inversely related to intensity (202, 198 and 190 bpm for 110, 130, and 150% intensity tests, respectively). It was interesting to note that during the 110% intensity tests of the females, a higher heart rate response was observed than in the peak oxygen uptake tests (197 bpm). No significant differences were reported in the heart rate responses of the males in the present study (194, 191, and 192 bpm for the three intensities, respectively) (Appendix 3c). The total work performed (J.kg^{-1}) by the females decreased from 631 to 324 between the 110 and 150% intensity tests. The work of the males did not decrease as much across the three increasing workloads (525 to 326 J.kg^{-1}) (Appendix 3b). These figures represent a relative work decrement of 38 and 48% for males and females, respectively. The females may have found the workloads at intensities greater than 110% too difficult and may therefore have terminated the tests before their true anaerobic capacity was exhausted. It may be speculated that the oxygen deficit data were not maximal at intensities greater than 110% and that this was reflected in the lower accumulated oxygen deficit scores of the females. Therefore motivational and perceived exertion factors could have prevented the females maintaining a plateau effect which was observed in accumulated oxygen deficits in the males in the present study.

A further concern with the AOD method applied to the children in the present study must lie with the potential of imprecision from the linear regression equation. Steady state data from the females in the present study produced linear regression equations with a mean correlation coefficient of .955. The corresponding value for the boys was .979. Neither of these values, however compared favorably with the precision of correlation coefficients from the linear regressions published previously for adults (.99, .998 and between .993 and .9995 from studies by Bangsbo et al. (1990) Gastin (1992) and Withers et al. (1991), respectively. A series of pre-tests were conducted and these tests indicated that the number of submaximal tests was somewhat limited on the CYBEX™ (Met, 100) cycling ergometer used in the present study. There appeared to be a substantial metabolic demand in the mechanical action of cycling at low intensities which resulted in the same oxygen uptakes over a range of low intensity workloads. No significant differences were obtained in the oxygen uptake values at intensities less than 50 watts. Significant oxygen uptake differences from workload increments, less than 20 watts were also difficult to obtain in smaller children.

Consequently, when maximal workloads occurred at 125 watts, there were restrictions on the number of data points from which steady state could be obtained for inclusion in the construction of a linear regression equation. Further research is required to determine the exercise device from which the greatest number of steady state submaximal data points may be obtained with children. Golden et al. (1991) recently published discrete oxygen uptake values in 5 watt increments from 20 to 100 watts using an electronically braked cycle ergometer (SIEMENS ELMA™). A large sample size of over 200 subjects may have enhanced the robustness of their steady state results. In the present study the smaller number of subjects could have made the statistical analysis more sensitive to random variation effects. There is a clear relationship between the number of data points that can be used and the precision of the linear regression equation which can be used to predict supramaximal energy demands.

An examination of the AOD results (when litres and $ml.kg^{-1}$) across the three intensities for the males in the present study, generally supports the concept that a plateau was occurring with increasing intensity . This finding compliments the work of Withers et al. (1991) and Gastin (1992) who associated the plateau effect across intensities with an indication of subjects reaching an exhaustive capacity within 60, and 90 seconds, respectively. Medbφ and co-workers (1988) obtained a plateau within 120 seconds from supramaximal treadmill performances of adults; however Medbφ et al. (1988) used a protocol which had predicted workloads which would exhaust the subjects within a given period of time. For workloads of less than two minutes the treadmill speed may have been too intense to allow full exhaustion of anaerobic capacities to occur in the adults studied by Medbφ et al. (1988). In the present study, the observed plateau within the responses of the males appeared to have been reached substantially earlier, than previously cited in adult studies (Gastin, 1992; Withers et al., 1991). Males in the present study demonstrated a maximal AOD after an average of approximately 47 s in the 150% supramaximal exercise test. A longer average duration of 74 s at 130%, did not produce any significant difference in the AOD score. Within the present study, the criteria for test termination was a frequency decrease to 60 rpm. Gastin (1992) terminated subjects at 80-85 rpm. Given a different criteria for termination the time to exhaustion values in the children in the present study could have occurred even earlier than 47 s. This finding may relate favourably to the work of Armon et al. (1991) who discussed a faster oxygen kinetics response in children, compared with adults during highly intense exercise.

Previously reported oxygen deficit values for children (Eriksson et al., 1973) used only one data point and assumed a similar efficiency response in all subjects in calculating oxygen deficits. Results from the previous study may not therefore be as accurate as the AOD method used in the present study. The anaerobic capacity of the children in the present study was less than the previously reported anaerobic capacity of adults (Gastin, 1992; Medbϕ et al., 1988, Medbϕ and Burgers, 1989; Withers et al., 1991). In absolute terms the anaerobic capacity of adults appears to frequently exceed 3.5 litres and reports of relative anaerobic capacity have approximated 50 $ml \cdot kg^{-1}$, or greater (Table 6.6). The observation of smaller absolute and relative anaerobic performances of children compared with adults is well supported in the literature (Bar-Or, 1983, 1987; Vandewalle et al., 1987; Zwiren, 1989). Sargeant (1989) believed that the factors which explained the difference between adults and children included; growth in the density of myofibular contractile properties of the fibres, improvements in connective tissue for the transmission of power, enhancement of neurological function, and advancement in the speed of muscle contraction. Anaerobic performances to exhaustion are also limited by the enzymatic processes in the muscle. Medbo (1991) asserted that the enzymes which enhance glycolytic lactate production and creatine phosphate breakdown in the muscle are known to have limits. A small amount of available research on children has indicated that these limits may be disproportionately smaller in children. For example, levels of phosphofructokinase, the rate-limiting enzyme in the glycolytic pathway, were less in pubertal males than adult males, but these levels increased with training (Eriksson et al., 1973). Reports of the relative concentration of lactate that can be produced, cleared and, or tolerated in children compared with adults remain controversial (Cumming et al., 1990; Eriksson et al., 1973; Macek, 1986). Lehmann et. al. (1981) reported that catecholamine levels following maximal aerobic exercise were reduced by 30% in children when compared with adults. It is possible that potential for anaerobic phosphagen release increases with maturational processes. Consequently, possible explanations for reduced performances in children compared with adults may include; less powerful functional and dimensional properties of the muscle (Sargeant, 1989), poorer glycolytic enzyme activity (Berg and Keul, 1988; Eriksson et al., 1973), less efficient respiratory responses under high intensity exercise conditions (Armon et al., 1991) and reduced catecholamine activity (Lehmann et al., 1981). Consequently, possible explanations for reduced performances in children compared with adults may include; less powerful functional and dimensional properties of the muscle (Sargeant, 1989), poorer glycolytic enzyme activity

Table 6.6: Summary table of some data on oxygen deficit values available in the literature

Authors (year)	n	Age (yrs)	Accumulated oxygen deficit (litres)	Accumulated oxygen deficit ($ml \cdot kg^{-1}$)	Exercise duration (s)	% effort
Medbø and Tabata	17	25	3.78	50.4∞	60	-
(1989)			4.06	54.2∞	120-180	
Graham and McLellan	4	22	4.38	60.2	145	120
(1989)						
Gastin et al., (1991)	8	22	3.48	47.6	45	
			3.58	49.0	60	
			3.63	49.6	90	
Gastin and Lawson	10	27	3.43	47.7	202	110
(1991)			3.48	46.5	101	130
Withers et al.,	6	25	3.18	45.42∞	30	
(1991)*			3.73	53.27∞	60	
			3.70	53.27∞	90	
Eriksson et al.,	8	11.5	1.48	46.5	300	100
(1973)#						
Present study	9	10.6	1.31	35.29	102	110
	(m)		1.35	37.11	62	130
			1.35	36.79	43	150
	9	10.7	1.71	40.39	146	110
	(f)		1.59	37.78	86	130
			1.36	31.80	53	150

* data from non-invasive study

not accumulated oxygen deficit method

∞ relative data approximated from mean body mass

(Berg and Keul, 1988; Eriksson et al., 1973), less efficient respiratory responses under high intensity exercise conditions (Armon et al., 1991) and reduced catecholamine activity (Lehmann et al., 1981).

Medbø and Burgers (1990) recently demonstrated that adult females had approximately 17% less AOD scores than males. In relative terms, the AOD results of the females in the present study were 14% greater than their male counterparts at 110%, but 14% less than the males at the 150% intensity. The observed difference in the intraclass correlation values (R) between the sexes reflected poorly on the repeatability of the female performances in the present study and may attenuate the variable findings in the females (Table 6.5).

A diverse spread of AOD scores was observed within the present study. The wide range of responses in this anaerobic characteristic is supported by the previous findings of diversity in anaerobic thresholds in children studied by Rowland and Green (1989) and Washington (1989). An explanation for the wide inter-subject variations may be found in further examinations of lean muscle tissue dimension and function, training status, genetic endowment and associated psychological factors.

Medbϕ and Tabata (1989) contended that after 30 s of intense exercise, work and accumulated oxygen uptake demands increased linearly with duration. Exhaustive exercise of less than 30 s duration incurred larger than expected proportions of oxygen uptake. According to Medbϕ and Tabata (1989), the accumulative effects of work and oxygen uptake demands over time also produced a decrease in peak rates of work and total energy release which declined hyperbolically in exhaustive exercise of between 30 s and 3 min duration. The rate of total energy release from males and females in the present study showed a decrease with duration and an increase with intensity. For example, for males and females, the respective rates decreased from a mean of 1.45 and 1.06 $ml \cdot kg^{-1} \cdot s^{-1}$ in the shortest durations (averaged at 150% intensity), to .98 and .86 $ml \cdot kg^{-1} \cdot s^{-1}$ for the longest durations (averaged at the 110% intensity). Medbϕ and Tabata (1989) also believed that while the amount of accumulated oxygen deficit remained constant between 30 s and 3 min, the rate at which it was released decreased with increasing time. Support for this response in the present study was demonstrated with a decrease in males from 0.88 to .39 $ml \cdot kg^{-1} \cdot s^{-1}$, and females from 0.60 to 0.29 $ml \cdot kg^{-1} \cdot s^{-1}$, from the tests of shortest to longest durations, respectively. Medbϕ and Tabata (1989) also suggested that as exercise duration increased there would be a increase in the rate of accumulated oxygen uptake. However, evidence of an increasing rate of oxygen uptake with duration was not as well supported in the present study with the rate of increase between the longest and shortest durations being only 0.1 and 0.06 $ml \cdot kg^{-1} \cdot s^{-1}$, for males and females, respectively.

Medbϕ and Tabata (1989) examined the relative importance of the aerobic and anaerobic processes in supramaximal tests. They emphasised that there was a substantial contribution from aerobic energy sources even in exhaustive exercise bouts of 30 s duration. Aerobic energy contributions during cycling exercise to exhaustion of 30 s, 1 minute, and 2 minutes duration were 40, 50, and 65 relative percent of the total energy release (Medbϕ and Tabata, 1989). Therefore Medbϕ (1991) speculated that a 50/50 split in aerobic/anaerobic contributions to exercise occurred after one minute of intense exercise. Similarly, Withers et al. (1991) reported a 49% aerobic contribution after 60 seconds of work. Within the three supramaximal workloads in the present study the percentage of aerobic contribution to the energy expenditure increased significantly with time and decreased with intensity. For example, in tests averaging 47 and 123 seconds of work, the aerobic contributions were 40.8 and 61.6%, respectively (Table 6.3). Supramaximal performances in the present study were not terminated at 60 seconds, however the aerobic contribution was 49% after an average of 73 seconds of work at the 130% intensity tests.

Saltin's (1990) main criticism of the AOD method has centred on an inability to accept that aerobic energy costs (efficiency) remained constant during highly intense exercise, i.e. efficiency decreases with intensity. If this was the case then the female response in the present study has reflected Saltin's perspective on decreasing efficiency i.e. efficiency at 110% was greater than efficiency at 130% and even greater than efficiency at 150%. Medbϕ (1991) contended that efficiency remained constant within the muscle regardless of intensity. Medbϕ et al. (1988) compiled energy equivalent data from invasive studies of muscle metabolites before and after intense exercise which accounted for the accumulated oxygen deficits predicted from the linear regression. Medbϕ (1991) postulated that anaerobic energy sources do not demand a higher ATP turnover rate than aerobic sources. Medbϕ and Tabata (in press) reported no significant difference in the efficiency demanded by type I (predominantly used under slow oxidative conditions) and type II muscle fibres (predominately used under faster glycolytic conditions). Medbϕ's (1991) defence of the concept of constant efficiency remained within the exercising muscle. He did however acknowledge that at highly intense exercise, efficiency may be changed by the inclusion of negative work or extra body movements such as upper body musculature. Coyle et al. (1992) recently reported a strong correlation between exercise efficiency and type I muscle fibres during submaximal exercise. They postulated that compared with type II fibres, type I fibres may have a lower ATP turnover rate which was reflected in a lower oxygen uptake. Both Medbϕ (1991) and Saltin (1990) have called for further research into efficiency demands during highly intense exercise. It should be noted that the downward trend in accumulated oxygen deficits observed in females in the present study was not evident with increasing intensities in the males, and has not been the case in previously published studies on adults (Gastin, 1992; Medbϕ et al., 1988; Withers et al., 1991). Foster et al. (1991) recently examined the running economy of prepubertal females during three submaximal walking speeds on the treadmill. Their results suggested that the economy ($kcal \cdot min^{-1}$) of the 7-11-year-old females was less than previously reported data from older females and data from males of a similar pre-pubertal age. However, Gastin (1992) postulated that the process of a linear regression may account for any delta changes in efficiency in the increasing metabolic response with intensity. Medbϕ (1991) also stressed a preference for obtaining steady state values from exercise at high percentages of VO_2max as these were closest to the supramaximal conditions.

From research conducted with adults we know that anaerobic capacity improved with training, that accumulated oxygen deficits obtained sprint-trained athletes have had up to 30% greater anaerobic capacity than endurance-trained athletes (Medb ϕ and Burgers, 1990). Troup et al. (1991) also reported a 30% gain in oxygen deficits following a sprint training program in swimmers (1.62 to 2.17 litres). Medbϕ (1991) believed that anaerobic capacities were not only capable of changing with training but would also vary within the same athlete depending on the muscle mass activated. This was supported in a study by Barzdukas et al. (1991) who demonstrated that the oxygen deficits in 13 elite male swimmers performing freestyle (2.4 litres), were significantly less than oxygen deficits recorded from breaststroke (2.8 litres). The authors concluded that swimming breaststroke had involved the use of a larger muscle mass and therefore demanded a higher anaerobic energy contribution than performances in freestyle. The anaerobic capacity of 12 international kayakers (45.91 $ml.kg^{-1}$) was reported to be relatively less than other elite athletes because of the involvement of a smaller muscle mass (Terrados et al., 1991). There is however a dearth of information available on similar training responses in pediatric populations.

The non invasive, challenging nature of the maximal AOD method for determining the anaerobic capacity of subjects make it an attractive protocol for use with children. However, the relatively small sample size and confounding results between males and females limit conclusions in the present study. From the present study, further validation research is evident in the areas such as the potential range of the equipment and protocol to be employed, obtaining optimal characteristics from steady state tests for the linear regression equation to accurately predict supramaximal performances, standardizing a criteria for obtaining maximal exhaustive performances and optimal motivational techniques to obtain exhaustive performances. Once the limitations of the maximal AOD method are resolved and the protocol has been appropriately modified for use with children the quantification of an anaerobic capacity may be a valuable research protocol in applied fields of training and performance.

Chapter Seven

Study Four

Measuring Maximal Accumulated Oxygen Deficit in Children Utilizing Isokinetic Exercise Conditions.

Measuring Maximal Accumulated Oxygen Deficits in Children Utilising Isokinetic Exercise Conditions.

Abstract

Anaerobic capacity was assessed in 7 male and 6 female children (aged 10.8 and 10. 7 years, respectively) using the maximal accumulated oxygen deficit (AOD) method on a CYBEX™ (Met, 100) isokinetic cycle ergometer. The method which has been previously described (Study Three) was used under "all-out" isokinetic conditions in this study. This differs from Study Three because in this previous study the children worked against a constant load. The children performed two "all-out" tests on an isokinetic ergometer. The AOD values for the males were not significantly different between trials (1.34 and 1.41 litres, and 35.6 and 37.7 and $ml{\cdot}kg^{-1}$, for trials one and two, respectively) (M±SEM). Similarly there were no significant differences in the AOD values for the female children between trials (1.41 and 1.37 litres and 31.6 and 34.6 for $ml{\cdot}kg^{-1}$, for trials one and two, respectively). Over the two tests the respective peak and mean power results revealed no significant differences between the sexes (307.4 and 192.4 w for males and 274.3 and 192.6 w for females). Intraclass correlation coefficients (R) for the AOD results in litres and $ml{\cdot}kg^{-1}$ in the tests were stronger in the males (0.956 and 0.952) than the females (0.862 and 0.891), respectively. It was concluded that the isokinetic testing produced AOD results which were reliable in children and also were comparable to those from the children in Study Three.

Measuring Maximal Accumulated Oxygen Deficits in Children Utilising Isokinetic Exercise Conditions.

Introduction

In children the peak oxygen uptake tests are a well accepted means for determining maximal aerobic power. however, measuring the capacity of anaerobic sources of energy production appears to be a more controversial task. Maximal accumulated oxygen deficit (AOD) has been used recently as a method for determining the anaerobic capacity of adults (Hermansen and Medbϕ, 1984; Medbϕ, 1991; Medbϕ et al., 1988; Medbϕ and Tabata, 1987; 1989). The method now appears to be a well accepted and reliable technique for assessing anaerobic capacity. Since the inception of the AOD method (Hermansen and Medbϕ , 1984), various exercise modes such as running, cycling, swimming and kayacking. have been adopted in order to elicit maximal anaerobic performances (Barzdukas et al., 1991; Gastin 1992; Graham and McLellan, 1989; Medbϕ et al., 1988; Medbϕ and Tabata, 1989; Terrados et al., 1991; and Withers et al., 1991).

The assessment of anaerobic capacity using the AOD method in children however, has received limited attention within the literature. Study Three recommended an examination of different exercise devices in order to identify whether different exercise modalities may provide better precision in the results for the pediatric populations. In the previous study (Study Three) a capacity in AOD was demonstrated when children were tested at efforts requiring between 110 and 150 % VO_2 max. using a constant load protocol on a cycle ergometer. Isokinetic devices, such as the CYBEX™ (Met, 100) generally involve inertial forces at the onset of exercise and by definition, entail no variation in angular acceleration once the isokinetic velocity is reached. Consequently, alterations to acceleration and deceleration rates which may be increased by fatigue are more stable under isokinetic conditions. Sargeant (1989) indicated that the normal relationship between body weight and leg muscle function would vary considerably as a child is growing. He postulated that having an accommodating resistance may enhance the selection of optimal testing conditions for child-based populations.

The AOD work previously performed by children involved maintaining 90 rpm at constant power workloads predicted to equal 110, 130, and 150 relative percent of peak oxygen uptakes (Study Three). However, the constant power tests were not terminated until the cadence decreased to between 70 and 60 rpm. Under constant power supramaximal conditions, efficiency demands may have deviated from the established power-O_2 relationships because of changes in pedal frequencies. To assist in the promotion of optimal performances, and to ascertain individually-preferred workloads under supramaximal conditions an isokinetic cycling device was used with the children. Thus, the purpose of the present study was to determine the AOD results of children using an isokinetic cycle ergometer (CYBEX™, Met 100) in an all-out effort with the pedal frequency fixed at 90 rpm to exhaustion. In using the isokinetic device it was hypothesised that the children would demonstrate individual preference for workrates which could then be compared with results previously obtained under prescribed and constant workrate conditions (Study Three).

Methods

The subjects were 13 children (7 male and 6 female), aged 10.9±0.2 years (M±SEM). The children were normal, healthy volunteers who attended the same inner suburban primary school from which the subjects in a previous study had volunteered (Study Three). Physical characteristics of the subjects are presented in Table 7.1. Subjects and parents provided written consent after being informed verbally and in writing of the experimental conditions and protocols. These conditions were approved by the ethics committee of Victoria University of Technology.

During an orientation visit to the laboratory the children were required to practise riding the CYBEX™ cycle ergometer against varying load stresses, while maintaining a cadence of 90 rpm. The peak oxygen uptake of the children was assessed using an incremental exercise protocol to volitional exhaustion. The testing protocols for peak oxygen uptake and anaerobic capacity using the AOD method have been previously described (Chapters Three, Study Three, and Appendix 3a).

The CYBEX™ (Met, 100) cycle ergometer provided screen displays of time, power, and pedal frequency throughout all testing. During peak oxygen uptake and steady state tests, metabolic data were measured by open circuit analysis of expired air as previously described (Chapter Three). Heart rate was monitored by a PE-3000 Sports Tester.

A 5 minute warm up at power output of 50 watts followed by a 5 minute rest interval preceded the all-out isokinetic testing. During all out isokinetic effort tests Douglas bags were used to collect expired air. Analysis of the supramaximal expired air of subjects has also been previously described.

All out isokinetic effort tests were conducted on two separate days to determine reliability. During the all-out isokinetic effort tests the children cycled supramaximally at a fixed pedal frequency of 90 rpm. speed and power output data were provided every two-seconds during these tests and used as a criterion for test termination (CYBEX™, Met Emulator software, Ball State University, 1991). The test was terminated when power output decreased to that corresponding to 95% of peak oxygen uptake.

Statistical analysis involved programs for descriptive data and independent t-tests (Minitab, 1988). A Series of 2 x 2 univariate ANOVAs, for sex and trial number were applied to performance variables from all out isokinetic effort tests (BMDP, 1985). Reliability of performances between the two all out isokinetic effort tests was calculated from intraclass correlation coefficients (R). Newman-Keuls multiple comparison post hoc analyses were used wherever applicable (Kirk, 1962).

Results

No significant differences were reported in the physical characteristics between males and females (Table 7.1). Similarly the maximal effort data revealed no differences between the sexes in peak VO_2 in $l \cdot min^{-1}$, maximal heart rate, RER max, and maximal workrate (Table 7.2). The males obtained a significantly higher relative peak oxygen uptake scores than the females (50.1±2.2, and 43.3±2.0 $ml \cdot kg^{-1} min^{-1}$, respectively) [$t(10)2.26$, $p \leq 0.047$].Similar results in the characteristics of the children in the present study and the children tested in Study Three can also be observed in Tables 7.1 and 7.2.

No significant interactions were apparent between sex and the two trials from the series of univariate ANOVA tests conducted on the AOD data in litres, $ml \cdot kg^{-1}$, the work performed under all out isokinetic conditions, and the time taken to exhaustion (p = 0.53, 0.72, 0.21 and 0.68, respectively). No main effects differences were reported between sexes in the respective male and female AOD results in litres and $ml \cdot kg^{-1}$, work performed ($J \cdot kg^{-1}$) and time to exhaustion (s) (Appendix 4a). The differences between the sexes approximated 0.0 litres, 3.6 $ml \cdot kg^{-1}$, 57 $J \cdot kg^{-1}$, and 7 s (Figure 7a). No main effect differences were reported between trials in the respective tests one and two for AOD in litres, work performed ($J \cdot kg^{-1}$) and time to exhaustion (s). These differences approximated 0.01 litres, 8 $J \cdot kg^{-1}$ and 0 s (Figure 7b). A significant difference occurred between trials one and two only when AOD results were expressed in relation to body mass ($p \leq 0.02$). These values were 33.8±2.6 and 36.2±3.0 $ml \cdot kg^{-1}$ for tests one and two, respectively.

Table 7.1: Descriptive characteristics of children in Studies Three and Four

Sex	Age yr	Mass kg	Height cm	BSA* m^2
Present study				
m	10.82	37.76	144	1.23
	(0.3)	(1.2)	(2.3)	0.0
f	10.72	39.62	148.2	1.26
	0.3	2.3	4.4	0.1
Study Three				
m	10.6	37.21	144.6	1.23
	(0.2)	(1.25)	(1.8)	(0.02)
f	10.6	41.38	149.9	1.38
	(0.3)	(2.60)	(3.5)	(0.05)

M+SEM

* Body surface area (m^2) [Du Bois and DuBois, 1916]

** comparison between sexes, significance, $p \leq .05$

Table 7.2: Maximal effort profiles of children in Studies Three and Four

Sex	VO_2max ($l \cdot min^{-1}$)	VO_2max ($ml \cdot kg^{-1} min^{-1}$)	HR max bpm	RER* max	WL max watts
Present study					
m	1.86	50.1	197	1.21	150
	(0.01)	(2.2)	(3)	(0.02)	(8)
f	1.70	43.3**	200	1.22	150
	(0.13)	(2.0)	(3)	(0.02)	(13)
Study Three					
m	1.99	53.9	199	1.13	172
	(0.05)	(2.3)	(2)	(0.01)	(4)
f	1.72	43.3**	197	1.11	165
	(0.12)	(1.1)	(2)	(0.02)	(11)

M±SEM

* Respiratory Exchange Ratio

** comparison between sexes, significance, $p \leq 0.05$

Figure 7a : Performance means for male and female children when two trials were combined for: (i) AOD (litres), (ii) AOD (ml·kg^{-1}), (iii) work (J·kg^{-1}), and (iv) time (s).

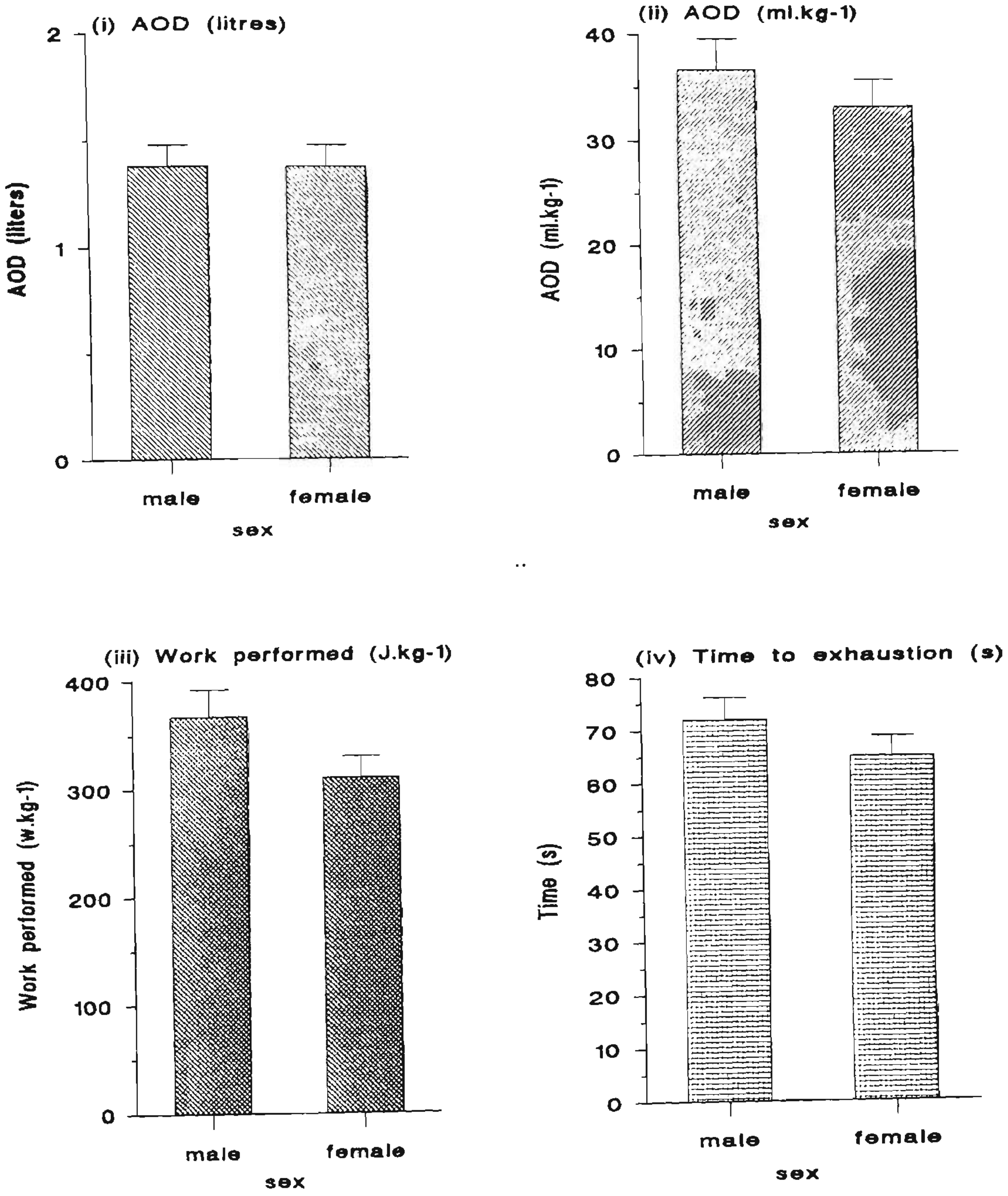


Figure 7b : Performance means for male and female children when two trials were combined for: (i) AOD (litres), (ii) AOD (ml·kg^{-1}), (iii) work (J·kg^{-1}), and (iv) time (s).

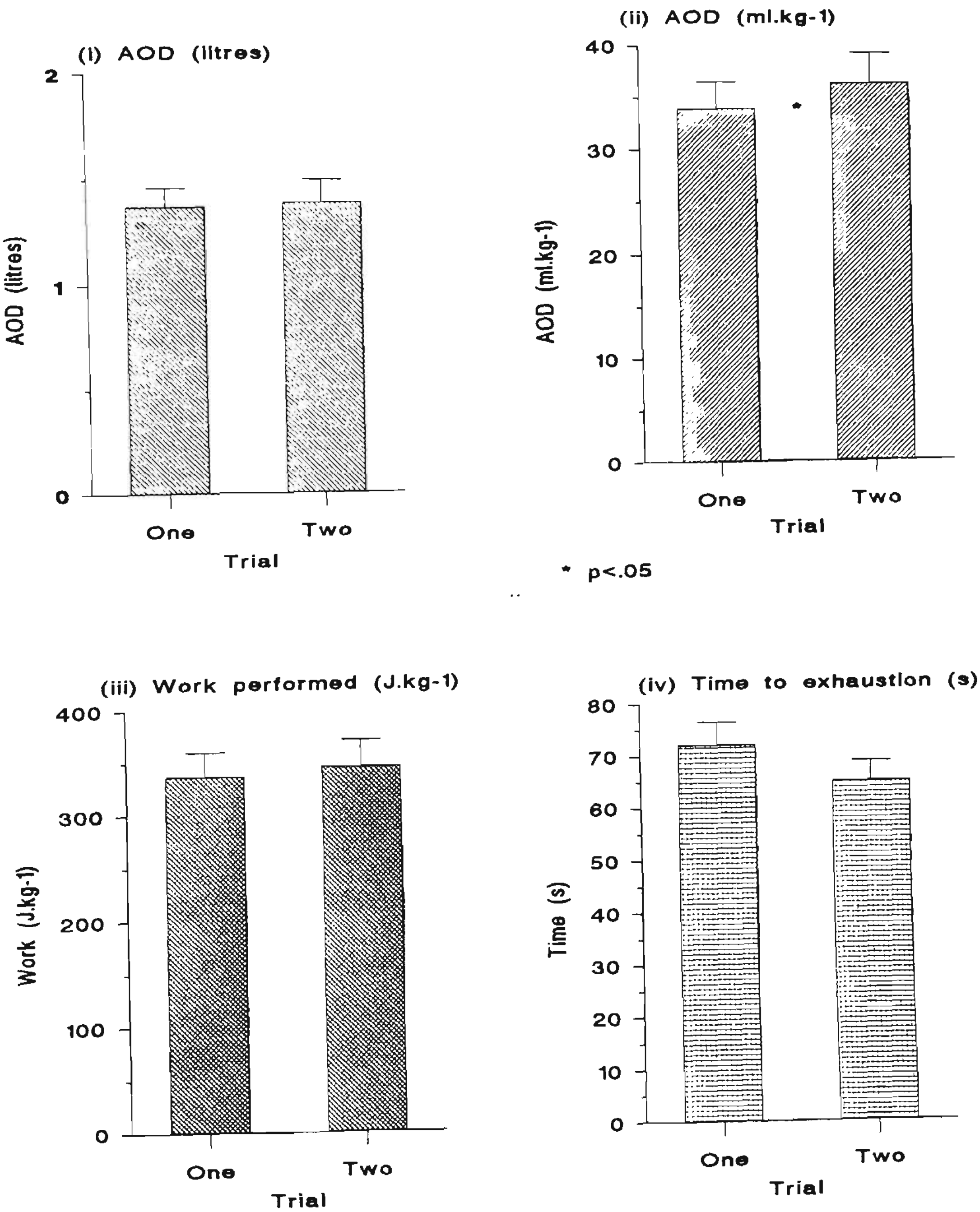


Table 7.3: Power outputs from isokinetic supramaximal testing in male and female children

Sex	PP (w)	MP (w)	PP.kg^{-1} (w·kg^{-1})	MP.kg^{-1} (w·kg^{-1})	F.I. (%)
m	307.4 (14.0)	192.4 (7.0)	8.2 (0.4)	5.1 (0.2)	71.0 (3.0)
f	274.3 (21.0)	192.6 (15.3)	6.9* (0.3)	4.8 (0.2)	68.7 (2.7)

M±SEM

* comparison between sexes, significance, $p \leq 0.05$

Overall, power output responses from the two all out isokinetic effort tests were similar between males and females (Table 7.3). When the results from both tests were averaged the relative peak power (relPP) of the females was significantly less than the males (6.9±0.3 and 8.2±0.4 w·kg^{-1}, respectively, $p \leq 0.02$). Power output during supramaximal performances was additionally used to predict the percentage of peak oxygen uptake at which the children performed. When expressed as a relative percent of the peak oxygen uptake, the peak power outputs for males and females represented 221±9 and 195±7%, respectively ($p \leq 0.02$). Mean power values from the two tests were not significantly different and represented 144±4, and 143±6% of peak oxygen uptake scores for the males and females, respectively.

The relative contributions of aerobic and anaerobic energy in each test were determined by expressing the accumulated oxygen uptake as a percentage of the predicted accumulated oxygen demand. The aerobic energy contribution was significantly different between the two trials (56.5±2.4, and 51.0±2.2 %, for tests one and two, respectively, $p \leq 0.047$), but it was not significantly different between sexes (56.3±2.5 and 50.8±2.1 %, for males and females, respectively, $F(1, 11)$ 2.05, $p \leq 0.018$) (Appendix 4b).

Table 7.4 demonstrates the reliability of the data from intraclass correlation coefficients (R) from the present study and Study Three. In the present study the R values from accumulated oxygen deficits in litres and ml·kg^{-1} revealed more reliable performances from males (0.956 and 0.952) than females (0.862 and 0.891), respectively. This trend was also supported in Study Three where the AOD results in litres and of male children (0.81 and 0.92) appeared to be more reliable than the results from the females (0.79 and 0.55).

The rate of energy release is the quotient of AOD and time to exhaustion (Medbφ and Tabata, 1989). In the present study no significant difference between males and females occurred in the rate of O_2 demand (1.18±0.04 and 1.04±0.08 ml·kg^{-1}·s^{-1}, respectively) and anaerobic energy release (0.52±0.04 and 0.52 ±0.04 ml·kg^{-1}·s^{-1}, respectively). The rate of O_2 uptake of the male and female children (0.66±0.03 and 0.52±0.02 ml·kg^{-1}·s^{-1}, respectively) was however, significantly different ($F(1,11)8.91$, $p \leq 0.01$).There were no significant differences in the rates of oxygen demand, O2 uptake and anaerobic energy release between trials ($p \leq$ 0.3, 0.2, and 0.11, respectively). (Table 7.5 and Appendix 4c).

Table 7.4 : Intraclass correlation coefficients (R) from two isokinetic supramaximal cycling bouts

Sex	n	Accumulated O_2 deficit (litres)	Accumulated O_2 deficit (ml·kg^{-1})	Exercise duration (s)	Work w
ISO					
m	7	.96	.95	.57	.88
f	6	.86	.89	.88	.98
CP					
m	9	.81	.92	.81	
f	9	.79	.55	.74	

ISO = isokinetic supramaximal exercise

CP = constant power supramaximal tests

Discussion

The AOD scores, work performed, time to exhaustion and the percentage of maximal effort at which the children worked under all out isokinetic conditions produced no significant differences between the sexes in the present study. This finding is supported by several authors (Bar-Or, 1983; Rowland, 1990) who have indicated that prior to puberty, no physiological differences exist to explain any observations of differences in performances between males and females. In the present study the only observed significant difference was in relative peak power between sexes and this may be attributed to the greater body mass of the females (39.6 kg) compared with the males (37.8 kg). It may be suggested that total body mass appeared to be a poor indicator of the explosive power output of the muscles in the females in the present study.

The variability of the Wingate anaerobic tests performances of children aged 6-12 years has recently been reported to be similar to adults (Chapter Five). Bar-Or (1987) reported that repeat performance correlation coefficients for the Wingate anaerobic test under standardised conditions ranged from .89 to .98 with most values being consistently higher than .94. Repeatability values for peak and mean power of .94 and .98, respectively were also reported by Bar-Or (1987) from tests with disabled children. In the present study differences between the two AOD tests were largely not significant (Figure 7b). The one exception to this occurred in the relative AOD scores for tests one and two. The difference between scores from the two tests was 2.4 $ml\cdot kg^{-1}$ which may be regarded as negligible. Overall, the minimal differences between tests suggested a good reliability of the testing protocol. Intraclass correlation values in the all out effort isokinetic protocol for the males in the present study were 0.96 and 0.95 in AOD scores in litres and $ml\cdot kg^{-1}$, respectively. Under constant power conditions, the corresponding intraclass correlations from the male children were 0.81 and 0.92 for AOD scores in litres and $ml\cdot kg^{-1}$, respectively (Table 7.4). For all children, RER values from supramaximal exercise in the two isokinetic tests (1.16, and 1.19) performed at 142.2 and 145.3 relative percent of peak oxygen uptake were substantially higher than RER values in the constant power tests (1.08, 1.07, and 0.98, for 110, 130, and 150% of peak oxygen uptake, respectively) (Study Three). These results suggest that the children in the present study may have worked harder. Under constant power conditions, (in Study Three) the children were required to maintain a revolution rate of 90 rpm against supramaximal resistances until exhaustion. In the present study however, the 90 rpm was maintained by the CYBEX™ ergometer and the children worked maximally against an accomodating isokinetic resistance. The greater intraclass correlation values under all out isokinetic exercise conditions compared with constant power conditions may indicate a greater reliability of the present protocol and may be perceived to be in agreement with the aforementioned arguments of Sargeant (1989) for the use of isokinetic devices for testing children.

One important finding of the present study has been the indication of similar anaerobic capacities from the AOD method in male children under constant power and isokinetic conditions. The mean respective AOD data in litres and $ml\cdot kg^{-1}$ from males across the 110, 130, and 150% of maximal aerobic capacity under constant power conditions were 1.3 and 36.41, respectively (Study Three), while the respective values from the present study were 1.37 and 36.7. In the constant load study male children demonstrated no significant differences from 110 to 150 relative percent of peak oxygen uptake (Study Three). This lack of change in AOD results after increasing intensities beyond 110% demonstrated the presence of a plateau, which in turn indicated the achievement of a capacity. The results of the present study also fell within this range of intensity (144%) reflecting that the technique under isokinetic conditions appears to elicit an effort that may also reflect a capacity.

In contrast to the performances of the males, the females in the constant load study demonstrated a significant downward trend of AOD results with increasing intensities (Study Three). AOD results in litres and $ml\cdot kg^{-1}$, respectively, of females in the present study (1.38, and 33.1), did not compare well to those obtained in the constant load study at workrates representing 110 (1.71 litres, and 40.4), and 130 relative percent of peak oxygen uptake (1.59, and 37.8). Study Three reported lower heart rate and RER values in the 150% (190 bpm and 1.02, respectively) compared with 110% intensity tests (202 bpm and 1.14) and it was suggested that this data may reflect a decreased effort by the females during the hardest intensity tests, resulting in the incomplete utilization of available anaerobic energy. In the present study heart rate and RER values averaged 197 bpm and 1.17, respectively. Subsequently, the constant power testing in the females in Study Three was reported to reflect depleted effort at higher intensities.

Table 7.5: Comparative data between the constant power and isokinetic responses to supramaximal exercise from male and female children.

	Constant		Power		Tests		Isokinetic tests	
	110%		130%		150%		144%	143%
	m	f	m	f	m	f	m	f
Duration	102	146	62	86	43	52	72	65
(s)	(20)	(16)	(10)	(6)	(4)	(3)	(4)	(4)
Work performed	525	632	390	449	326	325	367	310
($J \cdot kg^{-1}$)	(70)	(66)	(40)	(35)	(23)	(21)	(25)	(20)
Work	5.6	4.4	6.7	5.2	7.8	6.2	5.1	4.8
($w \cdot kg^{-1}$)	(0.3)	(0.1)	(0.4)	(0.1)	(0.5)	(0.2)	(0.2)	(0.2)
AOD	35.3	40.4	37.1	37.8	36.8	31.8	33.8	36.2
($ml \cdot kg^{-1}$)	(4.3)	(2.4)	(3.7)	(2.2)	(3.2)	(2.3)	(2.6)	(3.0)
% Aerobic	59.9	63.4	46.5	52.6	38.7	43.4	56.3	50.8
	(3.1)	(3.0)	(3.8)	(2.2)	(1.9)	(1.7)	(2.5)	(2.1)
Total energy rate	0.98	0.86	1.25	0.93	1.45	1.06	1.18	1.04
($ml \cdot kg^{-1} \cdot s^{-1}$)	(0.05)	(0.03)	(0.11)	(0.09)	(0.10)	(0.03)	(0.04)	(0.08)
O_2 uptake rate	0.65	0.52	0.56	0.50	0.55	0.46	0.66	0.52
($ml \cdot kg^{-1} \cdot s^{-1}$)	(0.03)	(0.08)	(0.02)	(0.06)	(0.30)	(0.08)	(0.03)	(0.02)
AOD rate	0.39	0.29	0.67	0.45	0.88	0.60	0.52	0.52
($ml \cdot kg^{-1} \cdot s^{-1}$)	(0.06)	(0.07)	(0.10)	(0.08)	(0.10)	(0.03)	(0.03)	(0.04)

M±SEM

Study Three and the present study measured AOD values on cycle ergometers under two different modes of use and similar results were obtained in the anaerobic capacity of male children.. A summary of the results from the two studies is presented in Table 7.5. In previous investigations, similar comparable oxygen deficits have been recorded with different testing apparatus. Withers et al. (1991) reported mean accumulated oxygen deficits from all-out performances on an air-braked cycle ergometer which were similar to results from Medbφ and Tabata (1989) who had used a Krogh™-type cycle ergometer (mean AODs of 53.3, and 54.2 $ml \cdot kg^{-1}$, respectively). In a study comparing constant power tests at 110, and 125 relative percents of peak oxygen uptake, to an isokinetic all-out protocol on a CYBEX™ ergometer, Gastin (1992) reported AOD values of 43.9±3.0, 44.1±1.8, and 42.2±2.0 $ml.kg^{-1}$, respectively, from nine male adults. The same author compared accumulated oxygen deficits from another group of subjects using a Monark cycle ergometer at a constant power workload representing 110 relative percent of peak oxygen uptake to results from subjects who performed an all-out protocol with reduced resistance. No significant differences were reported between these two AOD values (52.1±3.1, and 51.2±2.5 $ml.kg^{-1}$, respectively).

In the present study, over 50% of the energy released in both isokinetic tests was from aerobic sources for a duration of approximately 69 s. This compares favourably to the findings of studies with adults (Medbo and Tabata, 1989). In Study Three where children were tested using a constant power cycling exercise, the times for exhaustion at 130 and 150 % of maximal aerobic effort were 74 and 48 s, respectively. The aerobic contribution to energy sources was 49 and 40 % for 130 and 150% of maximal aerobic effort tests. The larger contribution from aerobic sources in the all out isokinetic performances of children compared with constant power conditions was attributed to the prolonged times to exhaustion in the present study. The criteria for test termination was accepted as the workrate predicted to represent 95% of peak oxygen uptake. The use of breath by breath data collection and analysis would enable the experimenter to precisely (and if necessary, retrospectively) identify the point at which individual's calculated oxygen uptake equalled actual oxygen uptake. In the present study, test termination was not as precise because of the limitations imposed by using the two second power output display on the cycle ergometer and the use of Douglas bag expired gases collection. It may be hypothesised that the isokinetic tests would have been made shorter with alternative technology. It could be hypothesized that test durations and aerobic contributions in the present study were too large to be predominantly anaerobic tests (Gastin, 1992). The challenge remains to obtain optimal test durations and intensities which are sufficient enough to exhaust anaerobic energy supplies, brief enough to minimise random error effects, and of an appropriate intensity to elicit the full potential of the subject.

Medbφ and Tabata (1989) reported that the aerobic component of the total energy demand increased proportionately with duration. Evidence supporting this concept is demonstrated from the male children tested when the constant power and isokinetic data were combined (Table 7.5). Important contributions of both aerobic and anaerobic energy sources are inherent in the AOD method. It has been suggested that AOD test of varying lengths may also serve as an indicator of aerobic performance (Medbϕ, 1991); however, the two indices are not necessarily related. Within the present study the relationship between aerobic and anaerobic indices was investigated. Correlation coefficients (r) of .59 and .31 for males and females, respectively were reported between the peak oxygen uptake scores and the accumulated oxygen deficit scores in the present study. The association between peak oxygen uptake and accumulated oxygen deficit performances could be described as positive, but only fair. Correlation coefficients were also calculated for the accumulated oxygen deficits ($ml \cdot kg^{-1}$) and the first ventilatory break point scores (expressed in relation to peak oxygen uptake scores) (Beaver et al., 1986, Walsh and Banister, 1988, Wasserman et al., 1990). The correlation values were -0.69 and 0.23, for males and females, respectively (Appendix 4d). This suggests that to a small extent, children in the present study with lower ventilatory break points, performed better in anaerobic tests for accumulated oxygen deficits.

Medbϕ and Tabata (1989) demonstrated that the rates of total energy release and anaerobic energy release ($ml \cdot kg^{-1} s^{-1}$) decreased hyperbolically with time and conversely, increased with intensity. In the present study the rate of release of the total energy demand in the isokinetic tests (which had corresponded to 144 relative percent of peak oxygen uptake) was less in the males than had been previously reported (Study Three) for the 150% intensity tests (1.19, and 1.45 $ml \cdot kg^{-1} \cdot s^{-1}$, for the two studies, respectively) (Table 7.5). This difference between the rates of release of the total oxygen demand is associated with the shorter duration of the 150% intensity (for 42 s) compared with the 144% isokinetic tests (for 72 s) in the present study. As a consequence of differences in the female samples, from the two studies on children, comparisons between females from the two studies were not considered valid. Medbϕ and Tabata (1989) also demonstrated that commensurate with increasing time to exhaustion, would be an increase in the rate of release for the accumulated oxygen uptake. The rate of release of oxygen uptake for males and females in the isokinetic tests (0.66, and 0.52 $ml \cdot kg^{-1} \cdot s^{-1}$, respectively) were similar to the rates of oxygen uptake release in the longest constant power tests at 110% intensity from the previous study (Study Three) (0.65, and 0.51 $ml \cdot kg^{-1} \cdot s^{-1}$ for males and females, respectively). Thus the rate of energy release in the children studied was closely related to the test duration and intensity.

In Study Three there was an expression of some concern over the accuracy of the linear regressions which predict supramaximal workrates. This included a discussion of the methodological limitations which restrict the number of data points for the construction of the linear regression. This may contribute to poorer accuracy in the correlation coefficients of the children compared with previous studies on adults. The number of data entries for the power-O_2 linear relationship in adults has ranged from between five (Bangsbo et al., 1990; Withers et al., 1991) and from 10 to 35 (Medbϕ and Tabata, 1989). Correlation coefficients from the linear regression equations which have been documented in adult studies were all above .99 (Bangsbo et al., 1990; Gastin 1992; Graham and McLellan, 1989; Withers et al., 1991). In the present study, selection of subjects was limited to children who could provide discrete differences in submaximal oxygen uptake responses at lower workloads on the CYBEX™ ergometer. In this way at least four to five data points were available for calculating the linear regression equations. Children with the lowest maximal work capacity still had a somewhat restrictive work range within which discrete steady state submaximal workloads could be obtained. The correlation coefficients from the linear regressions in the previous study for the males and females were 0.978 and 0.955, respectively (Study Three). In the present study these values for the males and females were 0.994 and 0.988, respectively. The smaller correlation coefficients from the linear regression equations of children when compared with adults, still reflect a need for research using alternative devices for stronger predictive equations.

At the onset of exhaustive exercise Medbϕ et al. (1988) reported that there was a substantial contribution from oxygen stored in the body; however, it was not recorded as a component of the aerobic sources of energy. They maintained that a proportional adjustment should be subtracted from the accumulated oxygen deficit scores because this contribution was aerobic rather than anaerobic. Oxygen stores predominantly from venous blood which may have been dissolved in body fluids, bound to hemoglobin or myoglobin, or even stored in the lungs, account for up to 6 ml.kg^{-1} of the oxygen deficit scores obtained in the average 77 kg man. Medbϕ et al. (1988) therefore subtracted the appropriate value from the estimations of the anaerobic energy contribution and added it to the accumulated oxygen uptake scores. These adjustments may be difficult to translate for child-based populations. Rowland (1990) reported that hemoglobin concentration increased through childhood and cited that a 10 year old child had only 72% (13.0 g/100 ml blood) of the mature adult level of hemoglobin. It may therefore be difficult to accurately estimate the fractions of oxygen stored and used by children at the onset of exercise. Withers et al. (1991) chose not to adjust this possible overestimation of the anaerobic contribution to exhaustive exercise. They believed that any overestimation may be compensated for by a possible underestimation of anaerobic deficits when discrepancies in mechanical efficiency were ignored. Medbϕ et al. (1988) and Medbϕ (1991) provided "in situ" research to suggest that at the muscular level, changes in efficiency do not occur under supramaximal conditions. Other investigators (Gastin, 1992; Withers et al., 1991) however acknowledge that estimations of supramaximal oxygen demand may not include the effect of stabilizing muscles, additional work from the cardiorespiratory musculature, and possible changes in substrate utilization under highly intense exercise conditions. Substantial evidence of disproportionate increases in oxygen uptake kinetics above the lactate threshold exists within the literature (Paterson and Whipp, 1991; Roston et al., 1987; Whipp and Ward, 1990). Zanconato et al. (1991) recently compared the oxygen cost and oxygen uptake dynamics of children to adults during one minute exercise bouts ranging from submaximal to supramaximal intensities of up to 100 and 125 relative percent of peak oxygen uptake. The authors reported significantly higher end oxygen uptake costs over the final 6 s of exercise in children compared with adults. The pattern of the children's response through increasing intensities differed significantly from the adults. The AOD method used in the present study was designed for adults and based on adult response patterns. Given the work of Zanconato et al. (1991) the validity of the AOD method may require closer analysis in child-based populations. The issues of changing and quantifying efficiency under supramaximal conditions remain unresolved.

Results from previous (Study Three) and present investigations which have used the AOD method in children, demonstrated some similarities in the pattern of responses by children compared with adults. In the all out protocols of Gastin (1992) subjects performed at 149% of peak oxygen uptake on a CYBEX™ cycle ergometer and 143% of peak oxygen uptake on a Monark cycle ergometer. The children in the present study exercised at a relative intensity of approximately 144% of peak oxygen uptake. The 'plateau' in the males in the constant power tests (Study Three) and the similarity in the results of the males for the constant power and isokinetic protocols are findings which have been supported in previous studies on adults.

Nevertheless, there are issues of precision in the method for children which need to be addressed. For example, precision in the criteria for test termination and a closer demonstration of supramaximal O_2 kinetics could be improved from the use of breath by breath data collection. However, some difficulties have been reported with children exercising at low intensities with this method of data collection (Unnithan et al., 1991). This may impair the precision of the linear regression equation which must be perceived as critical to the AOD method. Conversely the work of Armon et al. (1991) suggested that children have a decreased tendency to incur an oxygen drift at higher workrates. The ability to maintain steady state oxygen uptake values during high intensity exercise without additional non-metabolic oxygen uptake costs may be advantageous in the precision of the AOD method.

In conclusion the AOD method of determining the anaerobic capacity of children under all-out isokinetic conditions produced more reliable results than the constant power conditions in Study Three. The method in the present study produced results which overall were not significantly different between sexes and which were compatible with those children tested in Study Three. With further qualification and quantification of the method, AOD may be an exciting, non-invasive protocol to use in pediatric populations.

Chapter 8

Summary and Recommendations

Summary and Recommendations

The following pages provide a brief summary of the four studies conducted in this thesis. These pages also outline the issues from this research which remain unresolved and the recommendations for future research.

Summary of Study One

Study One examined power output responses in Wingate anaerobic tests (WAnTs) from the use of four different load applications; 0.04, 0.065, 0.075, and 0.08 kp·kg.BM. This study revealed that the choice of resistance for use in the Wingate anaerobic test with children requires careful examination. Children as young as 6 years elicited significantly lower peak and mean power performances from a resistance of 0.04 kp·kg.BM than from heavier resistances of 0.065, 0.075, and 0.08 kp·kg.BM. Of the three higher resistances experienced by the children, none provided a consistently and significantly higher power output than the others. Within the three higher resistances a significant age by sex by resistance interaction was demonstrated at the 0.065 kp·kg.BM resistance. Closer examination of the interaction revealed that it could be accounted for by less powerful performances of 6-year-old females than males and more powerful performances of 12-year-old females than males. Although it was not assessed, advanced pubertal maturation of 12-year-old females in comparison with males of a similar age may well be associated with these results. In contrast to the older children Gilliam et al. (1981) reported significantly lower peak heart rate intensity in females and males who were 6-7-years-old. The poorer performances of 6-year-old females compared with males may be postulated to be associated with a lower level of habitual physical activity. However, this response was only evident at the 0.065 kp·kg.BM resistance. Alternatively, the interaction observed at the 0.065 kp·kg.BM could have been an artefact of the study which was difficult to explain. The issue of an optimal resistance for the WAnT which could be applied to a broad age range of children remains unresolved. Perhaps more discrete increments of resistance such as 0.06, 0.08, and 1.00 kp·kg.BM may provide a more definitive solution to this problem. Resistances determined from body composition dimensions may also be more desirable and reflective of differing stages of maturation in child-based populations.

Summary of Study Two

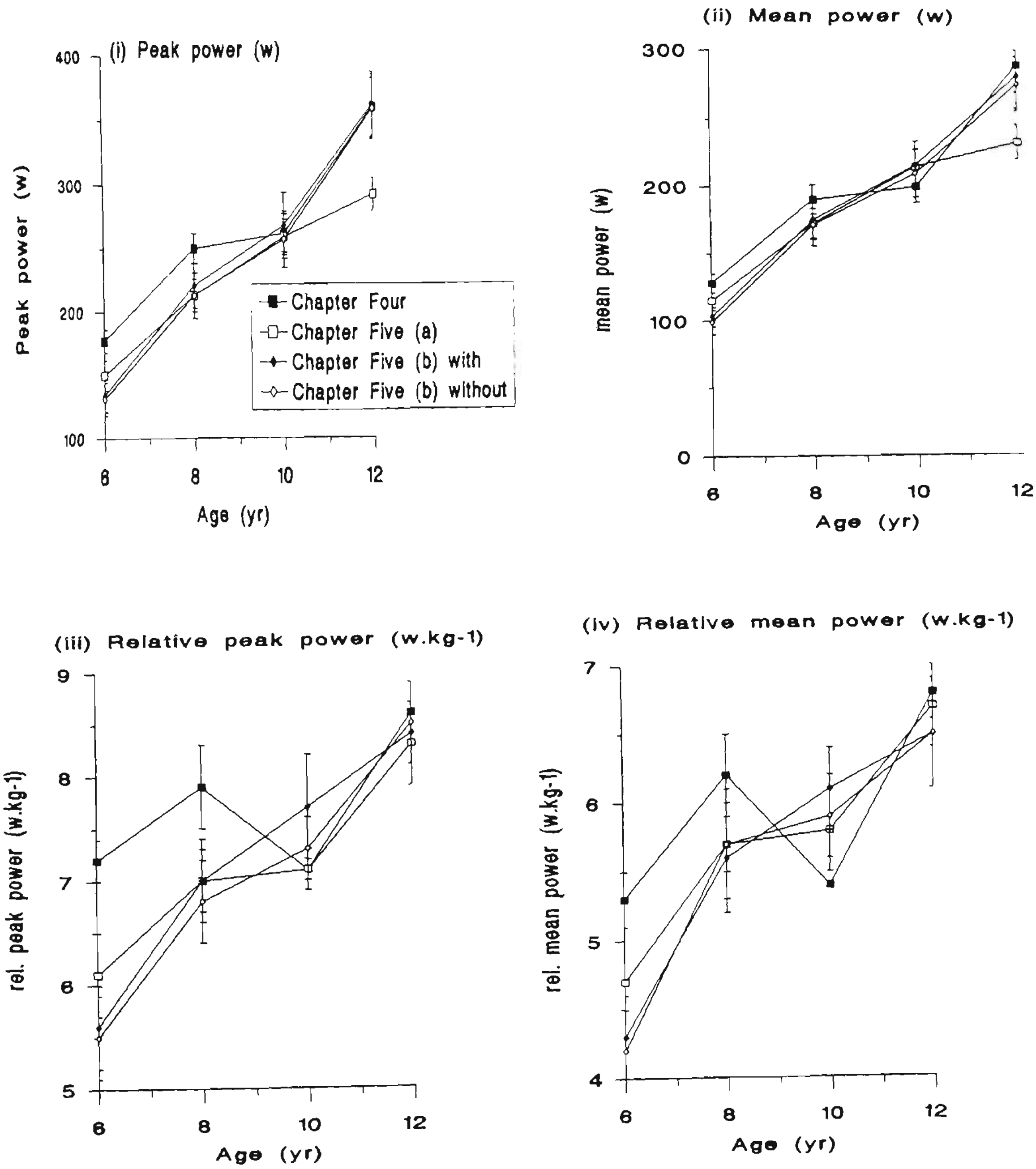
The second study also produced peak and mean power responses in WAnTs in children aged 6-12 years. The study however, only involved male children. Given the findings of Study One, the traditional 0.075 kp·kg.BM load application was chosen to examine the other aspects of WAnT performances of children. Study Two examined the variability of the anaerobic responses of male children aged 6-12 years during four repeated bouts of WAnTs on four separate occasions. The study supported the hypothesis that the peak and mean power performances of the male children during WAnTs did not vary more than adults performing a similar anaerobic task (Coggan and Costill, 1984).

Variability in fatigue index measurements, was however, substantially higher in these children than that repeated for adults (Coggan and Costill, 1984).The connection of the pedal frequency during the test to a computer programmed for on-screen feedback in the form of a game, significantly improved the coefficient of variability value in the fatigue index. Future studies of WAnT performances, in particular those reporting pre and post training test performances should consider the 7.2 and 7.3% coefficients of variation in peak and mean power performances from the population of the 6-12-year-old males tested in Study Two. The nature of the motivation in the form of on-screen feedback for consistency in performances in child-based testing was an important issue raised within this study and was a recommendation for future research. As a result the CYBEX™ cycle used in Studies Three and Four provided on-screen feedback throughout anaerobic performances of children.

Summary of Studies Three and Four

Studies Three and Four examined the anaerobic capacities of 10-11-year-old males and females with the accumulated oxygen deficit method. In Study Three, data from submaximal and peak aerobic performances were used to predict supramaximal workrates which represented 110, 130, and 150% of peak oxygen uptake. In this study the children cycled supramaximally against a fixed resistance. Their task was to maintain 90 rpm. The male children in Study Three demonstrated a plateau effect in their accumulated oxygen deficits across the three supramaximal intensities. This phenomenon had been demonstrated in adult males (Gastin, 1992; Hermansen and Medbφ, 1984). In the children tested the rates of anaerobic energy release decreased with time and increased with intensity. This pattern had similarly been observed in the work of Medbφ and Burgers (1990). The accumulated oxygen deficits of the females in Study Three did not display a plateaued response across the three supramaximal intensities of 110, 130, and 150% of peak oxygen uptake. The peak accumulated oxygen deficit for the females coincided with the supramaximal workloads representing 110%. Thereafter there was a decline in the accumulated oxygen deficits in the females in Study Three. This response was difficult to explain. The poorer accumulated oxygen deficit results of the females than males at intensities representing 130 and 150 relative percent of peak oxygen uptake were associated with observations of lower heart rates and RER values. It may be surmised that at high intensities the workrate demands for the girls were too intense to enable total exhaustion of the anaerobic energy system. Following Study Three the challenge of the accumulated oxygen deficit method appeared to be to find a supramaximal workload that was of suitable intensity to elicit maximal power output performances, yet would also be of sufficient duration to exhaust

Figure 8a: Summary of combined power output data from Studies One and Two (a) and (b) for (i) peak power, (ii) mean power, (iii) relative peak power, and (iv) relative mean power.



the anaerobic energy contribution. This finding prompted the use of an isokinetic mode of supramaximal cycling in the next study. Under isokinetic conditions the workrate at which the children maintained supramaximal effort was determined by the volitional exertion of the child. In Study Four the isokinetic mode of cycling under supramaximal conditions elicited similar accumulated oxygen deficits from the males and the females. The males in both Studies Three and Four also produced accumulated oxygen deficits which compared favorably. The accumulated oxygen deficits of children were similar in Studies Three and Four and when compared with values reported from adult populations were substantially smaller in both absolute (litres) and relative ($ml \cdot kg^{-1}$) terms.

Absolute and Relative Anaerobic Performances of Children

All four studies in this research, demonstrated that the anaerobic performances of children appeared to be age-related. This response was demonstrated in both absolute scores and when scores were expressed relative with body mass. A selection of results from Studies One and Two is provided in Figure 8a. This figure presents the WAnT performances of male children against a resistance of 0.075 kp·kg.BM. It demonstrates the similarity of age-related responses of the anaerobic characteristics of children.

In tests of aerobic capacity when scores are expressed relative to body mass (i.e., $ml \cdot kg^{-1} \cdot min^{-1}$), children's results compare favourably to those of adults. For example in Studies Three and Four, the mean absolute peak oxygen uptake scores for males and females were 1.92 and 1.71 $l \cdot min^{-1}$, respectively. Higher mean absolute maximal aerobic capacity scores in excess of 3.50 and 2.00 $l \cdot min^{-1}$, respectively have been reported in adult males and females (Mc Ardle et al., 1991). Wilmore and Costill (1988) reported studies where the average relative maximal aerobic capacity scores for 18-22-year-old males and females ranged between 44-50 $ml \cdot kg^{-1} min^{-1}$ and 38-42 $ml \cdot kg^{-1} min^{-1}$, respectively. The range of the relative peak oxygen uptake scores of the children in the present study was 43-52 $ml \cdot kg^{-1} min^{-1}$. Thus, expressing maximal aerobic capacity in relation to body weight appears to have an equalising effect between the two different age groups. The strength of the relationship between the body size and aerobic capacity has been thoroughly debated in the literature (Rowland, 1990; Winter, 1992). The relationship was most recently challenged by Bergh et al. (1991) who demonstrated that neither submaximal nor maximal aerobic performances were proportionally related to body mass. The authors cautioned against the validity of comparing two populations of differing body mass. Dimensional and functional characteristics of body mass may however, contribute substantially to differences in anaerobic performances of children and adults. In all four studies there were clear differences in the relative power output scores observed in anaerobic performances of children when compared with adults.

Table 6.6 presented absolute and relative anaerobic capacity values for children and adults from the maximal accumulated oxygen deficit scores. Relative maximal accumulated oxygen deficits scores were reported to be higher than 45 $ml \cdot kg^{-1}$ in the results from studies with male adults (Table 6.6). None of the male groups in the AOD investigations in Studies Three and Four had reported maximal accumulated oxygen deficit values exceeding 37 $ml \cdot kg^{-1}$, although the more mature sample of females in Study Three averaged 40 $ml \cdot kg^{-1}$ at a workload representing 110 relative percent of peak oxygen uptake. Postulations for poorer anaerobic performances of children compared with adults have been made by several authors (Armon et al., 1991; Bar-Or, 1983, 1987; Berg and Keul, 1988, Macek, 1986; Sargeant, 1989; Zwiren, 1989) and have been discussed previously (Chapter Two). These postulations contribute to the recommendations for future research into the anaerobic characteristics of children which include; precise identification of factors such as functional and dimensional properties of active muscle mass, the role of maturation on neuromuscular and catecholamine function, and the quantification or influence of respiratory factors which may differ in children, and, or mature with growth.

Comparison of relative power output performances of children

Three of the four studies profiled the specific anaerobic characteristics of peak and mean power outputs in children under highly intense exercise conditions. In Studies One and Two these characteristics were obtained using an all-out protocol against fixed resistances in WAnTs on a Monark™ cycle ergometer. Study One compared power output from several fixed resistances in pursuit of optimal performances. The 10 year old children in Study One produced relative peak and mean power outputs which were 7.1 and 5.3 and 7.3 and 6.1 $w \cdot kg^{-1}$, for males and females respectively, against the 0.075 kp·kg.BM load application. In Study Four the interface software linked into the CYBEX™ cycle ergometer provided 2-second power output data under isokinetic all-out conditions. In the isokinetic tests the 10-year-old children performed against a fixed revolution rate of 90 rpm. Although the isokinetic tests were conducted to exhaustion (72 and 64 s for males and females, respectively) the print out included mean power scores for the first 30s of the tests. This enabled the comparisons to be made of power output performances between Studies One and Four. In the first 30 s of their isokinetic supramaximal cycle to exhaustion, the 10 year old children produced relative peak and mean power outputs of 8.2 and 6.5, and 6.8 and 5.8 $w \cdot kg^{-1}$ for males and females, respectively. Thus, the isokinetic device appeared to elicit somewhat higher power output performances in males but not in females. Sargeant (1989) questioned the validity of fixed braking forces with children compared with adults because of disproportions in normal relationships of strength and body dimensions which are associated with growth. Sargeant (1989) further suggested that the ideal braking force at the start of a test may not necessarily be the optimal resistance towards the end of a test because of fatigue-inducing factors. His suggestion was that isokinetic devices may be the preferred option for use with children because they can determine their own braking force in all-out effort tests under isokinetic conditions. Power output values were not available for AOD performances under constant power conditions in Study Three. However, the values which were obtained under isokinetic conditions in Study Four may not be indicative of true peak power performances of this age group because tests were performed against 90 rpm and not the 120 rpm suggested as optimal for peak power performances by Sargeant (1989). The revolution rate adopted in the oxygen deficit method must allow for tests to be performed at relatively low submaximal intensities as well as supramaximal intensities. The true oxygen cost of these low intensities may indeed be masked by the substantial energy requirements of unloaded cycling costs at high revolution rates on the CYBEX™ cycle ergometer such as the 90 rpm used in submaximal performances in Studies Three and Four. Therefore one of the challenges of the oxygen deficit protocol with children is the choice of the ideal revolution rate which will ensure the optimal test validity in performances which are both submaximal and supramaximal.

Methodological issues of the AOD method

Permission for muscle biopsies is much more readily obtained from studies where the consenting subjects are adults rather than children. With adult subjects a great deal more information can be obtained in AOD studies because samples from muscle biopsies can be quantified for various "in situ" anaerobic characteristics. Yet even in adult populations there are still several issues of concern with the method. The greatest area of controversy centres on the validity of the extrapolation of an individual's submaximal responses into supramaximal conditions. A more detailed description of the arguments for and against the AOD method has been provided in Chapter Two. These issues have been summarised in Table 8.1.

The controversy surrounding the method becomes even more complex when children are measured for anaerobic capacity using the AOD method because no evidence of its use with children has previously appeared in the literature. For example, one of the problems was the small range of work capacities in which to establish a series of steady state values. In Studies Three and Four the lowest workload from which steady state could be obtained was 50 w. Pre-tests indicated that no significant differences existed between steady state VO_2 values obtained in exercise bouts at less than 50 w when children cycled at 90 rpm on the cycle ergometer used in Studies Three and Four. Obtaining the greatest number of steady state values between 50 w and a workload which would not induce an oxygen drift under steady state submaximal conditions was a problem which was not documented in the available literature on adults. The recommendation from this problem was therefore to investigate a series of apparatus to ascertain which one would allow for the greatest number of steady state points to be gained under submaximal conditions. A large number of steady state submaximal data points promotes a greater precision of the methods through the linear regressions which must be seen as the central focus of the method. Many challenges arose from the nature of equipment and, or protocol which may provide optimal performances in children. The challenges may be perceived as recommendations for future research which include, experimentation with alternative modes of metabolic data collection, alternative pedal frequencies, alternative criteria for determining exhaustion during performances, and nature of motivational techniques to obtain totally exhaustive performances in children.

Table 8.1: Summary of the issues of concern with the AOD method

Controversial Issues of the AOD method
• Validity of extrapolation from submaximal to supramaximal conditions (Saltin, 1990)
• Strong defence of similar rates of ATP and glycogen release in Type I and Type II muscle fibre (Medbφ, 1991; Vollestad et al., 1992)
• Accountability for energy equivalents of AOD from compilation of invasive studies. (Medbφ et al., 1988)
• Non-metabolic costs of supramaximal exercise under predicting O_2 costs. (Gastin, 1992, Saltin, 1990; Withers et al., 1991)
• Discrimination against fitter subjects with faster oxygen kinetics. (Withers et al., 1991)

Table 8.2 summarises several findings from the literature which may question the validity of the accumulated oxygen deficit method with children. For example, there are suggestions that the high intensity respiratory responses of children differ from those of adults (Armon et al., 1991; Zancanoto et al., 1991). Compared with the frequency of observations of oxygen drift under high intensity steady state conditions in adults, children have been observed to demonstrate this response less frequently (Armon et al., 1991). As previously mentioned, the precision of the prediction for accumulated oxygen demand largely depends on the maximal number of submaximal steady state points that can be provided for the linear regression. Theoretically, subjects in whom oxygen drift was not observed would be able to perform a larger number of higher intensity tests and provide relatively more steady state values for the linear regression equation than those subjects in whom oxygen drift had been observed. Thus according to the literature, children may have an advantage in sustaining relativley higher intensity steady state VO_2 values than adults. Additionally, Rowland et al. (1990) noted that the net mechanical efficiency of cycling in prepubertal children was not significantly different from adults under relative steady state conditions. The previous two points suggest that the accumulated oxygen deficit method may in fact be well suited to be adapted for use in children. The CYBEX™ cycle ergometer used in Studies Three and Four however, did not enable children to obtain

steady state responses at high intensities. More often than not, the children were unable to continue the high intensity submaximal workloads beyond four minutes. Thus, these tests could not contribute to the number of data points available for the linear regression equation. Perhaps this would not occur on a different cycle ergometer, or with exercise on a treadmill. The aforementioned factors may all be associated with the poorer correlation coefficients in the linear regression of children compared to adults and again indicate the need for child-based protocols in laboratory testing.

Table 8.2: Summary of the issues of concern with the use of the AOD method with children

Issues within the use of the AOD method with children
• Documented evidence that the child may be less susceptible to oxygen drift under relatively high steady state conditions. This characteristic is perceived as advantageous within the AOD method. (Armon et al., 1991)
• Inability in Studies Three and Four to achieve steady state under relatively high exercise conditions on the CYBEX™ cycle ergometer.
• Inability of children in Studies Three and Four to obtain correlation coefficients on the linear regression line which were as strong as those documented for adult populations. This may be associated with the smaller range of workloads in which steady state values could be measured on the CYBEX™ cycle ergometer.
• Suggestion that children may be more sensitive to hypoxic conditions than adults at the onset of exercise and move more rapidly into an aerobic preference for energy demand. (Springer et al., 1991)
• Inefficient ventilatory response patterns in children compared with adults. (Cooper et al., 1987)
• Evidence that children may respond in a different pattern to adults at the onset of highly intense exercise conditions. (Zanconato et al., 1991)

Withers et al. (1991) postulated that the accumulated oxygen deficit method discriminated against the subject who (through training) was able to move more quickly through the hypoxic phase at the onset of highly intense exercise than a less trained subject. The accumulated oxygen deficit of the trained individual was falsely recorded as smaller than it could have been if true anaerobic sources had been permitted to dominate. There is evidence in the literature on children that children also have an increased tendency to move from anaerobic to aerobic conditions rather rapidly. The findings of Poage et al. (1987) and Springer et al. (1988) would suggest that factors such as increased sensitivity to hypoxic conditions, and less storage capacity for CO_2 could lead to the postulation that differences in the child's oxygen kinetics may also impair a true indication of the capacity of the anaerobic system at the onset of exercise. If children are highly sensitive to hypoxic conditions such as those occurring at the onset of very intense exercise, then assumptions about constant efficiency from extrapolations for supramaximal conditions may not be as accurate in child-based populations compared to adults. Therefore predictions of accumulated oxygen demand may be even more underestimated in children than adults. However, this effect may well be negligible in exercise bouts of 45 s or greater in supramaximal exercise designed to exhaust the anaerobic energy capacity. Consequently there are several existing areas of contention in the use of the accumulated oxygen deficit method with pediatric populations. Some of the methodological issues (Table 8.1) may be addressed in the near future with experiments of a relatively simple design. It is however, the validity of the assumptions underlying the method which must be perceived as the greatest challenge for pediatric work physiologists. Even if all the adult controversies were resolved, the question would still remain of whether or not the prediction of supramaximal oxygen demands can be directly or proportionally used with child-based populations.

A greater understanding of the suitability of the accumulated oxygen deficit method for determining the anaerobic capacity of children can only be obtained through further experimentation (Table 8.2). Anaerobic capacity needs to be obtained in the future with a variety of protocols on a number of cycle ergometers as well as treadmill protocols. For example Medbφ et al. (1988) used a 10% incline in their AOD tests on a treadmill. Since the completion of the four studies presented in this thesis, further experimentation has occurred in our laboratory with children using the AOD method and a treadmill protocol which involved a 4% grade (Carlson et al., 1992). With a sample of eight 11-year old males, similar results have been obtained to those in Studies Three and Four for AOD results at 110 and 130% intensity tests (1.43 and 1.12, respectively). However at speeds predicted to represent 150% of peak aerobic capacity, the children obtained significantly less in accumulated oxygen deficit scores (0.71 litres). The authors believed that the small incline of the treadmill forced the speeds at the highest intensity to be too great to allow for exhaustion of total anaerobic energy supplies. Another study has commenced on the effect of a 6% treadmill incline for AOD tests conducted with children. These initial findings with children are in contrast to a recent report of increasing accumulated oxygen deficits with increasing treadmill inclinations in a sample of six adults (Olesen, 1992). The author claimed that accumulated oxygen deficits of 40, 72 and 69 $ml \cdot kg^{-1}$ for treadmill inclines of 1, 15 and 20% could not soley represent the recruitment of greater muscle mass at the higher treadmill inclination. He contended that at the equations from tests at a lower treadmill incline (1%) constructed regression equations which underpredicted true oxygen demands of the exercise in comparison to the equations used for higher gradients. He attributed the underestimation of oxygen costs to differences in the role of stored elastic energy and differences in the ratio of eccentric to concentric work between performances at low and high gradients on the treadmill. The co-ordination and ability of the child to cope with the skills of running at very steep inclines may preclude a similar result in child-based populations.

General Recommendations

The anaerobic capacity of children is yet to be established in cross-sectional as well as longitudinal studies. A developmental profile of the anaerobic capacity through childhood and adolescence from both cross-sectional and longitudinal studies would substantially contribute to the understanding of the responses of young children to anaerobic stimuli. Additional work on the consolidation of the AOD method may enable training studies to be conducted in children over a variety of ages and for varying amounts of time. Training studies have proven to effectively improve the anaerobic capacity of adults from differing populations (Barzdukas et al., 1991; Medbϕ and Burgers, 1989). The degree of relative improvement to be expected from training interventions remains an unknown quantity in children. Within the literature, profiles of anaerobic capacities of specific populations have also contributed valuable information about the effects of long term training within specific areas of physical activity (Barzdukas et al., 1991; Terrados et al., 1991). Therefore one of the recommendations from this thesis that child-based investigations continue to expand the foundation of knowledge of the anaerobic characteristics of children.

Although each of the four studies involved protocols and equipment which had been carefully modified for use with children, at the conclusion of the studies, the need for further adaptations became apparent. In all four of the studies changes to experimental procedures, protocol or equipment in future studies were recommended. A substantially greater body of knowledge would exist if all of these recommended studies are conducted. The recommendations for all four studies have been outlined in Table 8.3.

With a consolidation of the validity of the AOD method in pediatric population, testing could be extended to research into the applied fields of training and performance. Within this thesis a reasonable association has been found with the power output performance in the AOD method after 30 s of work and the power outputs from the Wingate anaerobic tests. Study Four also denoted a fair relationship between the children who produced a low first ventilatory breakpoint and those with high oxygen deficit scores, particularly in the male children. Stronger evidence is needed to link the AOD method to those of which have previously been used to profile anaerobic characteristics in children. The non invasive, challenging nature of the accumulated oxygen deficit method for determining anaerobic capacity makes it an attractive protocol for use with children.

Table 8.3: Recommendations for future adaptations or experimentations with equipment and or protocols in assessing the anaerobic characteristics of children

Study	Recommendations to equipment and, or protocol
One	Experimentation with more discrete load increments e.g. 0.06, 0.08, 0.10 kp·kg.BM.
	Inclusion of measurements such as a child-based formula for lean thigh volume.
Two	Experimentation with different computer-based game-type feedback on the screen during performances of WAnTs.
Three and Four	Experimentation with different revolution rates, modes of exercise, metabolic analysis equipment, criteria for exhaustion, and status of training in children.
	Correlations between AOD method and traditional methods of assessing anaerobic characteristics in children.

In order to identify potential and, or improvement in anaerobic performances of children, a sound knowledge of appropriate means of testing performances needs to be available. In a limited way the present research contributes to a greater understanding of the anaerobic testing and anaerobic characteristics of children. It is anticipated that future laboratory testing of these characteristics will adapt several of the aforementioned recommendations. Ultimately it is hoped that a fuller understanding of the anaerobic characteristics will be linked to more realistic expectations of children from those professionals who are concerned about the quality of coaching and teaching in pediatric populations.

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Appendices

Appendix 1a:

Varying loads -Peak power (w)

Age (yr)	Sex	0.04	Resistance 0.065	(kp·kg.BM) 0.075	0.08
12	m	228 (17)	316 (20)	361 (25)	353 (21)
	f	244 (12)	407 (32)	350 (30)	383 (30)
10	m	189 (12)	286 (17)	262 (15)	291 (18)
	f	188 (9)	267 (14)	265 (10)	297 (18)
8	m	167 (12)	222 (14)	250 (12)	240 (17)
	f	131 (10)	185 (14)	196 (13)	211 (14)
6	m	113 (6)	154 (7)	177 (9)	171 (8)
	f	81.5 (3)	122 (7)	149 (8)	138 (16)

M±SEM

Factorial analysis - Peak power

	F	*df*	*p*
Resistance	*261.7*	*3, 201*	*0.001**
R x S	*3.59*	*3, 201*	*0.014**
R x A	*10.42*	*9, 201*	*0.001**
R x S x A	*4.42*	*9, 201*	*0.001**

lean power (w)

	Resistance	(kp·kg.BM)	
0.04	0.065	0.075	0.08
189 (15)	259 16)	289 (20)	290 (21)
204 (11)	305 (23)	284 (24)	319 (25)
158 (9)	209 (17)	199 (12)	226 (16)
156 (8)	215 (11)	218 (6)	236 (13)
130 (8)	187 (11)	190 (11)	183 (12)
102 (8)	155 (19)	166 (12)	171 (12)
86 5)	119 (5)	128 (7)	132 (6)
62 (4)	91.3 (8)	111 (8)	106 (11)

0.08
8.4 (0.2)
3.6 (0.6)
7.8 (0.3)
.8 (0.3)
.5 (0.4)
.2 (0.2)
.7 (0.2)
.0 (0.6)

- *Mean power (w)*

F	*df*	*p*
237.77	*3, 201*	*0.001**
1.17	*3, 201*	*0.323*
7.91	*9, 201*	*0.001**
2.28	*9, 201*	*0.018**

*01**
23
*01**
*1**

Appendix 1d:

Varying loads - Relative mean power ($w \cdot kg^{-1}$)

Age (yr)	Sex	0.04	Resistance 0.065	(kp·kg.BM) 0.075	0.08
12	m	4.4 (0.1)	6.2 (0.2)	6.8 (0.2)	6.9 (0.2)
	f	4.6 (0.2)	7.0 (0.5)	6.4 (0.4)	7.4 (0.4)
10	m	4.2 (0.1)	5.7 (0.4)	5.4 (0.0)	6.1 (0.3)
	f	4.1 (0.1)	5.8 (0.2)	6.1 (0.2)	6.4 (0.3)
8	m	4.1 (0.2)	5.7 (0.2)	6.2 (0.3)	6.1 (0.3)
	f	3.5 (0.1)	5.3 (0.1)	5.7 (0.1)	5.8 (0.1)
6	m	3.5 (0.1)	4.7 (0.2)	5.3 (0.2)	5.3 (0.2)
	f	2.7 (0.0)	3.9 (0.2)	4.9 (0.3)	4.6 (0.4)

M±SEM

Factorial analysis - Relative mean power ($w \cdot kg^{-1}$)

	F	*df*	*p*
Resistance	*259.68*	*3, 201*	*0.001**
R x S	*0.75*	*3, 201*	*0.523*
R x A	*3.09*	*9, 201*	*0.001**
R x S x A	*1.73*	*9, 201*	*0.084*

Appendix 2a:

Part One - Peak power (w)

Age (yr)	Trial 1	Trial 2	Trial 3	Trial 4
12	294 (17)	303 (10)	291 (11)	286 (17)
10	257 (12)	254 (17)	259 (13)	269 (17)
8	206 (14)	220 (16)	209 (13)	218 (18)
6	147 (11)	154 (14)	147 (13)	153 (12)

M±SEM

Factorial analysis - Peak power (w)

	F	*df*	*p*
age	*22.79*	*3, 28*	*0.001**
trial	*0.98*	*3, 84*	*0.406*
age x trial	*0.69*	*9, 84*	*0.717*

Appendix 2b:

Part One - Mean power (w)

Age (yr)	Trial 1	Trial 2	Trial 3	Trial 4
12	231 (14)	241 (13)	233 (11)	225 (13)
10	213 (14)	211 (15)	217 (9)	217 (15)
8	172 (14)	176 (10)	168 (9)	175 (11)
6	119 (9)	120 (10)	106 (10)	114 (10)

M±SEM

Factorial analysis - Mean power (w)

	F	*df*	*p*
age	*22.35*	*3, 28*	*0.001**
trial	*1.16*	*3, 84*	*0.331*
age x trial	*1.14*	*9, 84*	*0.344*

Appendix 2c:

Part One - Relative peak power ($w \cdot kg^{-1}$)

Age (yr)	Trial 1	Trial 2	Trial 3	Trial 4
12	8.3 (0.4)	8.6 (0.4)	8.2 (0.5)	8.2 (0.5)
10	7.0 (0.3)	6.9 (0.4)	7.1 (0.3)	7.3 (0.4)
8	6.8 (0.4)	7.2 (0.2)	6.9 (0.2)	7.1 (0.3)
6	6.0 (0.4)	6.3 (0.5)	6.1 (0.4)	6.2 (0.3)

M±SEM

Factorial analysis - Relative peak power ($w \cdot kg^{-1}$)

	F	*df*	*p*
age	*6.80*	*3, 28*	*0.001**
trial	*0.94*	*3, 84*	*0.427*
age x trial	*0.53*	*9, 84*	*0.850*

Appendix 2d:

Part One - Relative mean power ($w \cdot kg^{-1}$)

Age (yr)	Trial 1	Trial 2	Trial 3	Trial 4
12	6.7 (0.3)	7.1 (0.3)	6.8 (0.2)	6.5 (0.3)
10	5.8 (0.3)	5.7 (0.4)	6.0 (0.2)	5.9 (0.3)
8	5.8 (0.3)	5.9 (0.2)	5.5 (0.2)	5.7 (0.2)
6	4.9 (0.3)	4.9 (0.4)	4.3 (0.4)	4.7 (0.4)

M±SEM

Factorial analysis - Relative mean power ($w \cdot kg^{-1}$)

	F	*df*	*p*
age	*8.47*	*3, 28*	*0.001**
trial	*2.06*	*3, 84*	*0.111*
age x trial	*1.78*	*9, 84*	*0.084*

Appendix 2e:

Part One - Fatigue index (%)

Age (yr)	Trial 1	Trial 2	Trial 3	Trial 4
12	28.0 (1.9)	30.4 (2.2)	30.7 (2.0)	31.7 (2.9)
10	27.6 (4.6)	29.9 (3.3)	23.4 (5.0)	28.7 (4.3)
8	30.6 (4.6)	34.1 (2.8)	42.5 (5.8)	37.8 (3.6)
6	32.8 (5.1)	43.1 (8.1)	34.3 (3.7)	38.0 (4.6)

M±SEM

Factorial analysis - fatigue index (%)

	F	*df*	*p*
age	2.12	3, 28	0.120
trial	1.56	3, 84	0.204
age x trial	1.17	9, 84	0.323

Appendix 2f:

Part two - Peak power (w)

Age	Trial 1		Trial 2		Trial 3		Trial 4	
(yr)	w	w/o	w	w/o	w	w/o	w	w/o
12	352	359	371	366	361	344	368	370
	(27)	(20)	(21)	(25)	(29)	(26)	(25)	(21)
10	261	262	284	255	262	264	267	248
	(19)	(17)	(32)	(29)	(26)	(21)	(27)	(22)
8	231	217	227	222	207	212	220	202
	(20)	(17)	(21)	(18)	(12)	(26)	(21)	(13)
6	133	130	134	130	132	132	138	131
	(14)	(17)	(12)	(14)	(16)	(13)	(12)	(9)

w = with the presence of the feedback screen

w/o = without the presence of a feedback screen

M±SEM

Factorial analysis - Peak power (w)

	F	*df*	*p*
Age	*24.64*	*3, 16*	*0.001**
Feedback	*3.76*	*1, 16*	*0.070*
F x A	*0.39*	*3, 16*	*0.763*
Trial	*1.18*	*3, 48*	*0.327*
T x A	*0.73*	*9, 48*	*0.683*
F x T	*0.83*	*3, 48*	*0.483*
F x T x A	*1.15*	*9, 48*	*0.346*

Appendix 2g:

Part two - Mean power (w)

Age	Trial 1		Trial 2		Trial 3		Trial 4	
(yr)	w	w/o	w	w/o	w	w/o	w	w/o
12	275	279	288	285	280	258	283	277
	(25)	(15)	(21)	(25)	(25)	(24)	(24)	(17)
10	209	212	219	207	212	215	220	202
	(13)	(17)	(19)	(19)	(20)	(17)	(19)	(19)
8	180	178	175	178	171	169	175	160
	(14)	(15)	(17)	(16)	(14)	(21)	(17)	(11)
6	105	97	103	97	100	104	104	99
	(8)	(11)	(10)	(9)	(11)	(9)	(9)	(9)

w = with the presence of the feedback screen

w/o = without the presence of a feedback screen

M±SEM

Factorial analysis - Mean power(w)

	F	*df*	*p*
Age	*20.93*	*3, 16*	*0.001**
Feedback	*5.54*	*1, 16*	*0.031**
F x A	*0.10*	*3, 16*	*0.960*
Trial	*1.3*	*3, 48*	*0.285*
T x A	*1.11*	*9, 48*	*0.373*
F x T	*1.39*	*3, 48*	*0.256*
F x T x A	*1.55*	*9, 48*	*0.159*

Appendix 2h:

Part two - Relative peak power (w·kg^{-1})

Age	Trial 1		Trial 2		Trial 3		Trial 4	
(yr)	w	w/o	w	w/o	w	w/o	w	w/o
12	8.2	8.4	8.7	8.6	8.4	8.1	8.6	8.8
	(0.4)	(0.4)	(0.2)	(0.4)	(0.3)	(0.4)	(0.5)	(0.6)
10	7.5	7.5	8.1	7.3	7.5	7.5	7.6	7.1
	(0.3)	(0.1)	(0.6)	(0.5)	(0.5)	(0.3)	(0.5)	(0.5)
8	7.3	7.1	7.2	7.1	6.6	6.7	7.0	6.5
	(0.3)	(0.3)	(0.4)	(0.3)	(0.4)	(0.5)	(0.5)	(0.4)
6	5.6	5.5	5.7	5.5	5.6	5.6	5.6	5.6
	(0.5)	(0.6)	(0.4)	(0.5)	(0.6)	(0.4)	(0.3)	(0.3)

w = with the presence of the feedback screen

w/o = without the presence of a feedback screen

M±SEM

Factorial analysis - Relative peak power(w·kg^{-1})

	F	*df*	*p*
Age	*10.82*	*3, 16*	*0.004**
Feedback	*3.07*	*1, 16*	*0.099**
F x A	*0.45*	*3, 16*	*0.722*
Trial	*1.05*	*3, 48*	*0.380*
T x A	*0.76*	*9, 48*	*0.653*
F x T	*0.82*	*3, 48*	*0.490*
F x T x A	*0.99*	*9, 48*	*0.463*

Appendix 2i:

Part two - Relative mean power ($w \cdot kg^{-1}$)

Age	Trial 1		Trial 2		Trial 3		Trial 4	
(yr)	w	w/o	w	w/o	w	w/o	w	w/o
12	6.4	6.6	6.7	6.7	6.5	6.1	6.6	6.5
	(0.4)	(0.3)	(0.3)	(0.4)	(0.3)	(0.4)	(0.5)	(0.4)
10	6.0	6.1	6.3	5.9	6.0	6.1	6.3	5.7
	(0.2)	(0.2)	(0.3)	(0.3)	(0.3)	(0.3)	(0.3)	(0.4)
8	5.7	5.6	5.6	5.7	5.5	5.3	5.5	5.1
	(0.3)	(0.2)	(0.4)	(0.4)	(0.4)	(0.4)	(0.4)	(0.3)
6	4.5	4.1	4.4	4.1	4.3	4.4	4.1	4.2
	(0.3)	(0.4)	(0.4)	(0.3)	(0.4)	(0.3)	(0.3)	(0.3)

w = with the presence of the feedback screen

w/o = without the presence of a feedback screen

M±SEM

Factorial analysis - Relative mean power($w \cdot kg^{-1}$)

	F	*df*	*p*
Age	*9.93*	*3, 16*	*0.001**
Feedback	*4.20*	*1, 16*	*0.057*
F x A	*0.10*	*3, 16*	*0.961*
Trial	*1.54*	*3, 48*	*0.215*
T x A	*1.02*	*9, 48*	*0.434*
F x T	*0.72*	*3, 48*	*0.542*
F x T x A	*2.01*	*9, 48*	*0.059*

Appendix 2j:

Part two - Fatigue index (%)

Age (yr)	Trial 1 w	Trial 1 w/o	Trial 2 w	Trial 2 w/o	Trial 3 w	Trial 3 w/o	Trial 4 w	Trial 4 w/o
12	42.9	41.7	40.5	40.8	43.3	43.8	44.0	48.8
	(3.0)	(3.6)	(4.0)	(4.4)	(3.6)	(4.3)	(2.6)	(7.4)
10	32.9	28.7	32.8	33.8	31.5	31.0	31.9	24.9
	(1.8)	(3.6)	(5.0)	(3.3)	(2.3)	(3.3)	(4.0)	(5.9)
8	37.9	37.1	33.6	33.5	28.6	31.7	36.2	40.3
	(1.7)	(2.7)	(2.8)	(5.3)	(1.8)	(3.0)	(1.6)	(1.5)
6	35.6	33.9	34.8	41.6	41.2	40.3	39.1	40.5
	(6.4)	(2.2)	(1.2)	(5.2)	(5.3)	(4.2)	(1.8)	(3.7)

w = with the presence of the feedback screen

w/o = without the presence of a feedback screen

M±SEM

Factorial analysis - Fatigue index (%)

	F	*df*	*p*
Age	*7.88*	*3, 16*	*0.001**
Feedback	*0.06*	*1, 16*	*0.805*
F x A	*0.51*	*3, 16*	*0.678*
Trial	*0.50*	*3, 48*	*0.685*
T x A	*1.40*	*9, 48*	*0.213*
F x T	*0.48*	*3, 48*	*0.699*
F x T x A	*0.41*	*9, 48*	*0.924*

Appendix 3a

Sample of the methodology used to obtain accumulated oxygen deficit values

Subject 'Jack', Age = 11.1 years Body mass = 37.2 kg

VO_2 max = 2.01 $l.min^{-1}$

Steady state responses

Work load (w)	VO_2 ($l.min^{-1}$)
50	0.9
70	1.1
80	1.2
90	1.3
110	1.6

Linear regression from steady state data

y = a + b (x)

y = 0.30 + 0115 (workrate)

r = .993

Supramaximal predictions

Max VO_2 = 2.01 $l.min^{-1}$, Supramaximal VO_2 for 130% = 2.61 $l.min^{-1}$

Predicted WL for 130% intensity = $\frac{[y - a]}{b}$ = 200 watts

Sample of calculations for AOD

Time to exhaustion = 57.43 s (= 0.957 min)

Predicted O_2 for time = 2.61 ($l \cdot min^{-1}$) x 0.957 (min)

Σ = 2.49 (liters)

Actual O_2 for time = 1.12 ($l \cdot min^{-1}$) x 0.957 (min)

Σ= 1.07 (litres)

Accumulated O_2 deficit = Predicted O_2 for time- Actual O_2 for time

= 2.49 - 1.07

= 1.42 (litres)

= 38.17 $ml \cdot kg^{-1}$

Appendix 3b:

Accumulated oxygen deficit data at three supramaximal intensities

	O_2 D (litres)	O_2 D (ml.kg^{-1})	time to exhaustion (s)	work (J·kg^{-1})
M (Σ)	1.44 (0.60)	36.5 (1.3)	82 (7)	441 (33)
male (Σ)	1.34 (0.11)	36.4 (2.1)	69 (9)	414 (31)
female (Σ)	1.55 (0.10)	36.7 (1.5)	95 (9)	468 (35)
110% (Σ)	1.51 (0.12)	37.8 (2.5)	124 (13)	578 (48)
130% (Σ)	1.47 (0.10)	37.4 (2.1)	74 (6)	419 (27)
150% (Σ)	1.35 (0.10)	34.3 (2.0)	48 (3)	326 (15)
male 110%	1.31 (0.10)	35.3 (4.3)	102 (20)	525 (70)
male 130%	1.35 (0.10)	37.1 (3.7)	62 (10)	390 (40)
male 150%	1.35 (0.10)	36.8 (3.2)	43 (4)	326 (23)
female 110%	1.71 (0.21)	40.4 (2.4)	146 (6)	632 (66)
female 130%	1.59 (0.12)	37.8 (2.2)	86 (16)	449 (35)
female 150%	1.36 (0.12)	31.8 (2.3)	52 (3)	325 (21)

Factorial Analysis

	F (df) p	*F (df) p*	*F (df) p*	*F (df) p*
sex	*1.64 (1, 16) .22*	*0.00 (1, 16) .95*	*3.96 (1, 16) .22*	*1.64 (1, 16) .06*
intensity	*2.23 (2, 32) .14*	*2.08 (2, 32) .14*	*2.23 (2, 32) .14*	*39.3 (2, 32) .00**
S x I	*3.38 (2, 32) .04**	*3.52 (2, 32) .04**	*2.23 (2, 32) .14*	*1.96 (2, 32) .16*

M±SEM

Appendix 3c:

Accumulated oxygen deficit data at three supramaximal intensities

	RER#	heart rate (bpm)	% aerobic contribution	workload (w)
M (Σ)	1.04 (0.10)	195 (1)	507 (1.6)	232 (7)
male (Σ)	1.00 (0.01)	192 (1)	48.2 (2.4)	246 (11)
female (Σ)	1.09 (0.10)	197 (2)	53.1 (2.1)	220 (9)
110% (Σ)	1.51 (0.01)	197 (2)	61.6 (2.1)	194 (8)
130% (Σ)	1.09 (0.01)	1963 (2)	49.6 (2.3)	232 (10)
150% (Σ)	1.07 (0.01)	191 (2)	40.8 (1.4)	2726 (12)
male 110%	0.98 (0.00)	191 (2)	59.9 (3.1)	204 (12)
male 130%	1.03 (0.01)	194 (2)	46.5 (3.8)	245 (15)
male 150%	0.95 (0.01)	192 (1)	38.7 (1.9)	288 (18)
female 110%	1.14 (0.01)	202 (2)	63.4 (3.0)	183 (11)
female 130%	1.11 (0.01)	198 (3)	52.6 (2.2)	219 (13)
female 150%	1.02 (0.01)	190 (3)	43.4 (1.6)	257 (15)

Factorial Analysis

	F (*df*) *p*	*F* (*df*) *p*	*F* (*df*) *p*	*F* (*df*) *p*
sex	*10.31 (1, 16) .00**	*3.77 (1, 16) .01**	*2.46 (1, 16) .13*	*1.78 (1, 16) .20*
intensity	*9.37 (2, 32) .00**	*4.76 (2, 32) .01**	*59.41 (2, 32) .00**	*364.1 (2, 32) .00**
S x I	*0.23 (2, 32) .79*	*5.05 (2, 32) .01**	*0.23 (2, 32) .80*	*1.37 (2, 32) .26*

M±SEM

= respiratory exchange ratio

Appendix 3d:

Accumulated oxygen deficit data at three supramaximal intensities

	total energy demand rate (ml·kg^{-1}·s^{-1})	O_2 uptake rate (ml·kg^{-1}·s^{-1})	AOD rate (ml·kg^{-1}·s^{-1})
M (Σ)	1.08 (0.42)	0.54 (0.31)	0.55 (0.09)
male (Σ)	1.23 (0.13)	0.59 (0.03)	0.65 (0.08)
female (Σ)	0.93 (0.06)	0.49 (0.04)	0.45 (0.2)
110% (Σ)	0.89 (0.03)	0.58 (0.05)	0.34 (0.04)
130% (Σ)	1.09 (0.15)	0.53 (0.06)	0.56 (0.04)
150% (Σ)	1.25 (0.13)	0.50 (0.03)	0.74 (0.11)
male 110%	0.98 (0.05)	0.65 (0.03)	.39 (0.06)
male 130%	1.25 (0.11)	0.56 (0.02)	0.67 (0.10)
male 150%	1.45 (0.10)	0.55 (0.30)	0.88 (0.10)
female 110%	0.86 (0.03)	0.52 (0.06)	0.29 (0.07)
female 130%	0.93 (0.03)	0.05 (0.08)	0.45 (0.03)
female 150%	1.06 (0.0)	0.46 (0.0)	0.60 (0.0)

Factorial Analysis

	F (df) p	F (df) p	F (df) p
sex	*14.88 (1, 16) .001**	*8.58 (1, 16) .009**	*10.22 (1, 16) .001**
intensity	*38.57 (2, 32) .001**	*2.92 (2, 32) .068*	*63.23 (2, 32) .001**
S x I	*3.52 (2, 32) .041**	*0.69 (2, 32) .461*	*3.66(2, 32) .038**

M±SEM

Appendix 4a:

Accumulated oxygen deficit data at two supramaximal isokinetic intensities

	O_2D (litres)	O_2D ($ml.kg^{-1}$)	time to exhaustion (s)	work $J.kg^{-1}$
M (Σ)	1.38 (0.13)	35.0 (1.9)	69 (3)	341 (17)
male (Σ)	1.38 (0.10)	36.7 (2.9)	72 (4)	367 (25)
female (Σ)	1.38 (0.10)	33.1 (2.6)	65 (4)	310 (20)
test 1	1.37 (0.09)	33.8 (2.6)*	70 (4)	337 (23)
test 2	1.39 (0.11)	36.2 (3.0)	68 (4)	345 (25)
male test 1	1.34 (0.13)	35.7 (3.7)	72 (6)	357 (36)
male test 2	1.42 (0.16)	37.7 (4.7)	72 (6)	377 (40)
female test 1	1.40 (0.13)	31.7 (3.8)	66 (6)	313 (28)
female test 2	1.40 (0.16)	34.5 (3.8)	63 (5)	308 (31)
Factorial analysis	*F (df) p*	*F (df) p*	*F (df) p*	*F (df) p*
sex	*0.00 (1, 11) 0.975*	*0.40 (1, 11) 0.540*	*0.90 (1, 11) 0.363*	*1.46 (1, 11) 0.252*
test	*0.04 (1, 11) 0.845*	*6.64 (1, 11) 0.025**	*0.19 (1, 11) 0.668*	*0.63 (1, 11) 0.442*
sex by test	*0.41 (1, 11) 0.536*	*0.13 (1, 11) 0.722*	*0.17 (1, 11) 0.687*	*1.72 (1, 11) 0.216*

M±SEM

Appendix 4b:

Accumulated oxygen deficit data at two supramaximal isokinetic intensities

•	RER[#]	heart rate (bpm)	% peak O2 uptake	% aerobic contribution
M (Σ)	1.18 (0.01)	195 (1)	143.8 (2.7)	53.7 (1.7)
male (Σ)	1.19 (0.01)	193 (1)	144.2 (3.8)	56.3 (2.5)
female (Σ)	1.17 (0.01)	197 (3)	143.3 (4.0)	50.8 (2.1)
test 1	1.17 (0.01)	195 (2)	142.3 (3.5)	56.5 (2.4)*
test 2	1.20 (0.01)	195 (2)	145.3 (4.3)	51.0 (2.2)*
male test 1	1.18 (0.01	192 (1)	140.8 (4.2)	59.0 (3.1)
male test 2	1.21 (0.01)	194 (2)	147.6 (6.6)	53.6 (3.1)
female test 1	1.15 (0.01)	199 (4)	144.0 (6.1)	53.6 (2.7)
female test 2	1.18 (0.01)	196 (4)	142.6 (5.7)	47.9 (2.9)

Factorial analysis	*F (df) p*	*F (df) p*	*F (df) p*	*F (df) p*
sex	*1.03 (1, 11) 0.331*	*1.34 (1, 11) 0.271*	*0.01 (1, 11) 0.905*	*2.05 (1, 11) 0.180*
test	*1.90 (1, 11) 0.197*	*0.01 (1, 11) 0.924*	*0.50 (1, 11) 0.494*	*5.0 (1, 11) 0.047**
sex by test	*0.03 (1, 11) 0.862*	*3.57 (1, 11) 0.085*	*1.15 (1, 11) 0.307*	*0.00 (1, 11) 0.958*

M±SEM

= respiratory exchange ratio

Appendix 4c:

Accumulated oxygen deficit data at two supramaximal isokinetic intensities

	total energy demand rate ($ml \cdot kg^{-1} . s^{-1}$)	O_2 uptake rate ($ml \cdot kg^{-1} . s^{-1}$)	AOD rate ($ml \cdot kg^{-1} . s^{-1}$)
M (Σ)	1.12 (0.0)	0.60 (0.0)	052 (0.0)
male (Σ)	1.19 (0.0)	0.66 (0.0)*	052 (0.0)
female (Σ)	1.04 (0.1)	0.52 (0.0)*	052 (0.0)
test 1	1.11 (0.1)	0.62 (0.0)	050 (0.0)
test 2	1.14 (0.1)	0.57 (0.0)	054 (0.0)
male test 1	1.18 (0.1)	0.69 (0.0)	051 (0.1)
male test 2	1.20 (0.1)	0.63 (0.0)	053 (0.0)
female test 1	1.02 (0.1)	0.54 (0.0)	0.49 (0.6)
female test 2	1.06 (0.1)	0.50 (0.0)	0.55 (0.1)
Factorial			
analysis	*F (df) p*	*F (df) p*	*F (df) p*
sex	*1.18 (1, 11) 0.304*	*8.91 (1, 11) 0.012**	*0.00 (1, 11) 0.977*
test	*0.91 (1, 11) 0.359*	*1.90 (1, 11) 0.196*	*2.96 (1, 11) 0.113*
sex by test	*0.07 (1, 11) 0.802*	*0.11 (1, 11) 0.743*	*1.29 (1, 11) 0.280*

M±SEM

Appendix 4d: First Ventilatory Breakpoints detected in subjects in Study Four

Subject number	Gender	Peak VO2 ($ml \cdot kg^{-1} min^{-1}$)	% at which ventilatory breakpoint occurred
1	m	43.34	61.18
2	m	55.47	55.77
3	m	54.94	57.00
4	m	47.23	71.20
5	m	42.22	78.19
6	m	56.13	30.35
7	f	37.82	77.57
8	f	44.16	62.56
9	f	48.29	80.61
10	f	47.33	57.94
11	f	36.40	84.83
12	f	45.81	54.68

VUS